THE NORWEGIAN NORTH POLAR EXPEDITION

1893–1896

SCIENTIFIC RESULTS

EDITED BY

FRIDTJOF NANSEN.

VOL. IV.

THE NORWEGIAN

NORTH POLAR EXPEDITION 1893—1896

SCIENTIFIC RESULTS

VOLUME IV.

The Council of

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THE NORWEGIAN NORTH POLAR EXPEDITION

1893—1896.

SCIENTIFIC RESULTS.

VOLUME IV.

We shall be much obliged if the enclosed receipt for it could be signed and forwarded to Prof. W. C. BRØGGER, Christiania.

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Printed June 1902—February 1904.

XI.

DIATOMACEÆ

FROM THE ICE-FLOES AND PLANKTON OF THE ARCTIC OCEAN

BY

H. H. GRAN.

(WITH 3 PLATES).

During the Norwegian Polar Expedition 1893—96, Dr. Nansen and Dr. Blessing collected a number of samples containing microscopic algæ, especially Diatomaceæ. Some of them are plankton samples, taken with fine silk nets, from various depths, some of them samples of algæ from the ice-floes or from the channels in the ice, where the algæ floated about in great lumps during the summer when the ice was melted. As the plankton samples differed not a little from the others, I shall specially describe them first.

I. THE PLANKTON OF THE POLAR SEA.

The plankton samples that have been collected on previous expeditions in the Polar Sea, contained a considerable quantity of algæ, especially diatoms. It has therefore been a generally accepted idea, that the Polar Sea possesses an abundant vegetable plankton, at any rate in the summer.

The series of samples that Nansen brought home shows, however, that the great, deep Polar Sea is very deficient in plankton algæ, deficient not only in species, but also in specimens. North of the New Siberian Islands, in a latitude rather above 78° N., large quantities of diatoms were indeed found as plankton in October, 1893. It was principally only one species, however — *Chætoceras boreale* —, that appeared in very large numbers; *Chætoceras decipiens* and *contortum* in very much smaller quantities, the latter with spores. *Chætoceras boreale* and *decipiens* are oceanic specimens, while *Ch. contortum* is neritic. The plankton therefore consisted principally of oceanic diatoms.

At the same time, Nansen observed some newly-formed ice that was brown in colour. When he melted some pieces, a brown sediment came from them, consisting of plankton diatoms. The sediment was preserved in spirit, and has retained perfectly all its cell-contents with cell-nuclei and chromatophores. Some of the plankton diatoms found in this way in the ice, were the same species that were living at the same time as plankton; but in addition to these, there were also several especially neritic forms (vide p. 11). These occurred in the ice as spores. There is therefore reason to believe that not long before, they had been living as plankton, but on the arrival of autumn, had formed spores, and disappeared from the plankton.

All the plankton samples taken later during the expedition, contain only a few specimens of algæ, while at the same time there is quite an abundant animal life. There seem to be comparatively most in the autumn, in the winter, none. All the species that occur are purely oceanic, and their distribution, moreover, is almost cosmopolitan. I have only been able to discover the following species:

Chætoceras boreale,
— *decipiens,*
Coscinodiscus oculus iridis.

The last-named seems to occur in the greatest quantities; in one sample of deposit from newly-formed brown ice (October 15th, 1894), no inconsiderable quantity of it was found.

Table I. will give an idea of the scarcity of algæ in the samples.

It is difficult to understand how all the crustaceans (*Calanus finmarchicus*, etc.) that swarm in the upper strata of the Polar Sea, can find the means of sustaining life; I did not succeed in finding any trace of diatoms in their intestinal canal, and the plankton contained very little of their excrements.

II. THE DIATOMS UPON THE ICE-FLOES.

The samples taken upon the drift-ice, partly upon the ice-floes and at their edge, partly in the channels in the ice, are of greater botanical interest.

Diatoms have also been found during previous expeditions on the ice-floes in the Polar Sea, and they have been examined so thoroughly that

there is very little chance of finding new species in such localities. It will also be seen in the list of species that follows, that Nansen's samples contain comparatively few new forms, and the few new species that I have had to enter, differ from the most nearly allied forms only in characters that may easily escape observation.

Former investigations, on the other hand, have not shed light upon the conditions of life among these diatoms. The samples have in most cases been boiled with acid or heated without previous examination; and we have therefore not learned whether any of the species can live upon the ice, or whether they are to be regarded as more or less casual impurities, like the inorganic dust which often accompanies them.

The earliest information on the subject of diatoms on ice-floes that I have been able to find, is in *Cleve* and *Grunow's* paper [80][1] p. 3. Among the abundant material upon which the interesting work of these authors is based, there were also samples of mud and earth, which *Nordenskiöld* and *Stuxberg* had taken from ice in the Kara Sea in 1875—76, on the Swedish expedition to the Yenesei. But there were scarcely any diatoms in these samples, say the authors, and they contained only a few species. In the list that then follows, it is not stated which species were found on the ice.

During the Vega Expedition, *Kjellman* collected diatoms from ice-floes near Cape Wankarema in north-eastern Siberia. This collection has been examined by *Cleve* [83]. It consisted in a great measure of hitherto undescribed species. About half of the new species that Cleve describes in his report were from Cape Wankarema, most of the others being tropical forms. Some slides of this collection were distributed in Cleve and Möller's exsiccatæ, and attracted universal attention among students of diatoms, by their peculiar composition. Cleve says nothing as to how the diatoms occurred upon the ice-floes, nor yet whether they were alive when found. The majority of the species already known from other places were salt-water forms.

At about the same time, *Grunow* ([84] pp. 102, etc.) had an opportunity of examining a sample of diatoms, that was taken from the under surface

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[1] The works cited, a list of which will be found at the end of this paper, are indicated by the date of their publication in parentheses [ ] following the name of the author.

of an ice-floe, in latitude 74° 48′ 4″ N., and longitude 54° 52′ 8″ E., on the west coast of Novaja Semlja. It consisted principally of small forms with thin cell-walls, that in all probability have lived where they were found. Many of the species were the same as those found at Cape Wankarema, but some of the most characteristic of those forms were missing, e. g. *Navicula superba* with all its varieties (*N. sibirica, N. obtusa*), *Navicula Baculus* (= *Stenoneis inconspicua* var. *Baculus*), *Pinnularia quadratarea* with varieties (only var. *Stuxbergii* found), *Gomphonema kamtschaticum* var. *grœnlandica, Navicula kryophila,* etc.

When *Nansen* came back in 1889 from his Greenland expedition, he brought with him 2 samples of mud from the drift-ice on the east coast of Greenland. The diatoms were determined by *Cleve,* who found 16 species and varieties, with all of which he was acquainted from Cape Wankarema, 12 of them not having hitherto been found anywhere else. I here give a list of them from Nansen's work [92], p. 107. The forms known only from Cape Wankarema are marked with an asterisk.

Navicula Stuxbergii, Cl.
* — *imperfecta,* Cl.
* — *transitans,* Cl.
* — *superba,* Cl.
* — — v. *elliptica,* Cl.
* — *sibirica,* Grun.
— *subinflata,* Grun.
* — *algida,* Grun.
— *æstiva.*
* — *kryophila,* Cl.
* — — v. *gelida,* Cl.
* — *Baculus,* Cl.
* *Amphiprora kryophila,* Cl.
* *Nitzschia gelida,* Cl. & Grun.
* *Coscinodiscus lacustris* v. *hyperborea,* Grun.
* — *polyacanthus* v. *intermedia,* Grun.

These diatoms were dead when Nansen found them; it is probable that they had drifted with the ice from north Siberia, as Nansen and Cleve supposed.

In 1891, during *Ryder*'s expedition, a very large collection of diatoms was made by *N. Hartz* upon ice-floes off the east coast of Greenland. The collection has been thoroughly and minutely examined by Östrup [95]. In these samples too, all the forms characteristic of the samples from Cape Wankarema were found. Östrup does not, however, venture to draw any conclusion as to a connection between the ice in the two places; for the Greenland samples also contain some other species that are not known from Cape Wankarema. Some of these, it is true, are fresh-water forms, whose occurrence on the ice must be dependent upon chance circumstances; but others are marine, and occur in such large quantities that they are characteristic forms of the ice-samples. Östrup names, for instance, *Stauroneis Hartzii*, Oestr., *Navicula perlucens*, Oestr. and *Chætoceras septentrionale*, Oestr.. all newly-described species.

In any case, Östrup's specimens have some of them been dead when taken; the extract that is given from Hartz's journal shows that they were found in lumps, were as a rule white outside, but of a brownish green inside. This indicates that in the interior of the lumps, at any rate, cells might be found that had vitality. In certain cases, Hartz specially mentions that they are living, as for instance:

"Ice 42. July 16, 1891. Large, light brownish green lumps of living diatoms, some floating upon a lake on the ice, some lying at the bottom of shallow cylindrical hollows on the bottom of the lake. 74° 45′ N. Lat., 11° 42′ W. Long.".

In a supplement (l. c. p. 467), Hartz states his view as to the origin of the diatoms. He supposes some to have been carried out on to the ice by the wind, others by the rivers; but most of them are marine forms that may have been washed up in stormy weather, or frozen into the ice when this formed. "Those lumps that had been enclosed in the ice for any length of time, were bleached and colourless all through; other lumps, which had not lain so long in the ice, had only lost their colour on the outside, while inside they had retained their brownish green hue."

In 1892—93, *Vanhöffen* carried out some investigations in Karajak Fjord in West Greenland, which are of the greatest importance for a comprehension of these conditions. Vanhöffen has made a provisional statement on the subject in "Verhandlungen d. Gesellschaft für Erdkunde zu Berlin" [93]; a full

report has since been published [97], and I have myself elsewhere [97, 2] published a special description of the diatoms.

Karajak Fjord was covered with ice from the beginning of December until the beginning of June. During the months from November to February, there were very few diatoms in the plankton; but in March (March 24th, 1893), the quantity increased considerably, *Fragilaria* being the most abundant. At the same time, Vanhöffen found that the under surface of the ice was covered with a brown coating of diatoms, consisting of species that, for the most part, were also found on the ice-floes in the Polar Sea. *Nitzschia frigida, Fragilaria oceanica* and *Navicula septentrionalis,* Oestr. were the most numerous, the first two of these being also the predominating species in most of the samples from the Polar Sea. The specimens collected by Vanhöffen have undoubtedly been possessed of full vitality. They are preserved in alcohol, and their cell-contents are in a perfect state of preservation, so that the cell-nuclei and chromatophores can be studied in all their details.

These species were also found at the same time as plankton, and still more later on, in May. The chain-like species in particular increased to an extraordinary degree in the plankton *(Fragilaria, Achnanthes tæniata, Navicula septentrionalis* and *Vanhœffenii)* while the forms capable of motion, such as *Nitzschia, Pleurosigma* and the larger species of *Navicula (N. directa, N. transitans)* were only found in very small numbers.

Vanhöffen's investigations show that the diatom-flora of the ice consists of a community of algæ, which, for biological reasons, resort to the under surface of the ice, and are able to live there. It is probably the attraction of the light which makes them congregate under the ice. This algæ-community is composed partly of plankton forms *(Fragilaria, Melosira),* and partly of littoral forms, capable of movement, such as *Pleurosigma Stuxbergii* and *Navicula directa.*

The ice flora in the Karajak Fjord must be replenished every year by the neritic plankton of the fjord, and by the local littoral flora; in the Polar Sea, where the ice never disappears, algæ-communities of this kind may be frozen into the ice in the winter, and in the spring, if they have not in the mean time been killed, again develope.

Cleve, in an interesting treatise [96, 1] on diatoms from Baffin's Bay and Davis Strait, mentions that in a plankton sample from Cape Eglinton, he

found a number of the forms that are characteristic of the ice-floes in the Polar Sea. He supposes, and with very good reason, that they come from melted ice-floes that have drifted along the coast of Greenland.

Lastly, *Cleve* [98] has examined a sample of ooze taken by the Jackson-Harmsworth Expedition from a drifting ice-floe, 48 miles south of Belle Isle. Most of the forms contained in this sample were fresh-water forms, but there were also 17 true salt-water forms, and a large proportion of these were the same as those found near Cape Wankarema. Several, however, of the most characteristic Wankarema forms are wanting. Cleve says (l. c. p. 25):

"These figures prove that the ice-floe derives from the mouth of some river, but the fresh-water species do not indicate the precise spot. Some of the marine species are identical with those found on the drifting ice at Cape Wankarema and along the east coast of Greenland, but on the whole there is a considerable difference, as many of the most characteristic of the latter were not found. On the other hand, there is nothing against the supposition that the mud was derived from the shore of the Kara Sea, which seems most probable." [1]

The majority of the diatom-samples taken from the drift-ice during Nansen's expedition, were collected in the summer of 1894 in about 81° N. Lat. and 125° E. Long. Three of the samples Nansen obtained by melting newly-formed sea-ice that was remarkable for its brown colour. The sediment left after melting, and which consisted solely of diatoms, was preserved in alcohol. Two of these samples were taken in October, 1893, north of the New Siberian Islands, the third in October, 1894.

One sample that differed considerably from the others, Nansen took on an ice-floe in the Barents Sea, between Franz Josef Land and Novaya Zemlya, on the 8th August, 1896. Further mention will be made of it later on.

The samples may be classed according to their occurrence, in the following manner:

(1) Free-floating lumps in the channels between the ice-floes.

(2) Diatoms 'on the ice-foot', a margin projecting from the ice-floes, a foot or two below the surface of the water, and formed by the

[1] Since this was written, Cleve has published a paper: Mikroskopisk undersökning af stoft, funnet på drifis i Ishafvet 1899. Öfversigt af Kgl. Vetenskaps-Akademiens Förhandlingar 1899, No. 3. In a sample taken during the Swedish expedition to Spitsbergen, 1898, in 78° 21′ 48″ N. Lat. and 2° 45′ W. Long., he has found a great number of the species characteristic of the ice at Cape Wankarema.

more thorough melting of the ice on the surface of the sea, where the water is comparatively warm (see the surface-temperatures in Memoir IX, pp. 82—89).

(3) Diatoms in cylindrical holes on the ice-floes, on the bottom of fresh-water ponds not communicating with the open sea.

(4) Sediment obtained by melting newly-formed sea-ice.

1. The free-floating masses were of two kinds, (a) mucous greenish brown masses composed solely of *Melosira,* and often occurring in great abundance at a depth of about 1 metre, in the layer of fresh water formed by the melting of the ice. These mucous brownish masses very often formed almost continuous layers extending from floe to floe in the narrow water-channels. The *Melosira* evidently flourished here, and often grew very fast. (b) The other form of free-floating masses consisted of globular lumps, generally of a reddish colour, and with a diameter from quite small up to one or two inches, or even more. The bulk of each lump was generally formed of a large, globular alga with red cell-contents, which gave the lumps their reddish external colour. The latter were often living, but sometimes dead and colourless, and then the lumps looked quite white. Inside, the lumps have the more brownish green colour of the diatoms. These floating communities of algæ grew rapidly larger from day to day. They began as small floating lumps that were hardly visible, but could attain a considerable size. The lumps, as well as the mucous masses of *Melosira,* are generally found at the depth of about 1 metre below the surface, on the border between the fresh water formed during the melting of the ice, and the under-lying salt sea-water.

The lumps contain great quantities of diatoms, especially *Nitzschia* species *(N. frigida)* and *Fragilaria.* The cells of the diatoms have retained their contents, sometimes in a fairly good condition.

Others of them were dead, only empty cell-walls; probably the unfavourable hydrographic conditions, the great inequality in the salinity of the water, may have killed them.

2. The samples taken on the ice-foot exhibit, on the whole, the same composition as the lumps. *Melosira hyperborea,* however, generally predominates, while *Nitzschia frigida* occurred in the greatest numbers in most

of the free-floating lumps. As minor component parts in both kinds of samples, there are a great number of species, especially *Naviculaceæ*, that are identical with those Cleve has mentioned from Cape Wankarema.

3. The samples taken from holes in the ponds of fresh water on the surface of the ice-floes are, on the whole, poorer. They are all alike in containing numerous fragments and spores of plankton forms such as *Chæto-ceras boreale* and *decipiens* (fragments), *Coscinodiscus oculus iridis* (empty valves), *Chætoceras contortum, debile, diadema, teres, Thalassiosira gravida* (spores). But there are also species that have lived in these holes, as they appear in considerable quantities, and with their cell-contents; among these I would especially mention *Navicula subinflata* and *Caloneis kryophila.*[1]

4. The samples from the newly-formed sea-ice contain, for the most part, plankton forms, some of them vegetative cells, but more especially spores. There are also a certain number of species which are commonly regarded as bottom forms, as they are equipped for moving along the bottom, and are without the special requisites for floating (e. g. *Pleurosigma Stuxbergii, Navicula gelida*).

A detailed account of the contents of each sample will be found in a table at the end of this paper.

The species found in the samples from the Polar Sea may be classed under the following heads:

(1) True plankton forms.
(2) Species that are found living both in plankton and on ice.
(3) Species that are known from ice-floes only, or also as littoral forms.
(4) Fresh-water forms.

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[1] By the melting of the snow and ice on the surface of the floe-ice, ponds of fresh-water were formed on the floes everywhere in the neighbourhood of the Fram, during the summer of 1894. On the bottom of these ponds I soon observed small brownish spots or, as it were, accumulations of sediment. Upon examining this sediment I found, however, that it was composed partly of dead fragments of diatoms, *Chætoceras, Coscinodiscus,* etc., but to a still greater extent of living diatoms. By observing these brown spots in the ponds, I could now see how they rapidly grew larger from day to day, but by their absorption of the heat from the sun, the ice was melted away under them, so that they sank deeper and deeper into the ice, and small circular holes were formed often several inches deep and perhaps an inch or more in diameter. The bottom of these holes was gradually quite filled with a quantity of diatoms, which could easily be sucked up by a glass-tube. *F. N.*

(1) *True Plankton Forms.*

The number of true plankton forms is by no means small; the oceanic species occur as fragments, the neritic as spores. They are most numerous in a few samples taken in October, 1893, in latitude 78° 19′ N., longitude 136° 16′ E. The samples were obtained by melting ice that was of a brownish red colour. Plankton samples were taken at about the same time, that contained great quantities of *Chætoceras boreale,* but few diatoms besides *(Ch. decipiens, Ch. contortum).* The ice, on the other hand, besides cells of *Ch. boreale,* contained spores of the following species:

Chætoceras contortum,
— *debile,*
— *diadema,*
— *septentrionale,*
— *sociale,*
— *teres,*
— *Wighami,*
Thalassiosira gravida,
— *Nordenskiœldii,*
Actinocyclus alienus v. *arctica,*

as well as empty cell-walls of *Chætoceras decipiens* and *criophilum,* and cells of *Thalassiosira hyalina.* Some special ice-forms were also found, *Nitzschia, Fragilaria* and *Navicula* species. In some of the other ice samples, *Chætoceras Mitra* and *furcellatum* were found as well as the above-named plankton forms; and *Coscinodiscus oculus iridis* occurs rather frequently in the shape of fragments.

It will be seen that all these plankton forms are also found alive on the shores of Greenland, which, as regards plankton, have been more carefully investigated than any other arctic region. These species have a very wide distribution; they are probably circumpolar. The oceanic plankton species, *Coscinodiscus oculus iridis, Chætoceras boreale, criophilum* and *decipiens* may be considered to be cosmopolitan. Among the neritic forms, some, such as *Chætoceras contortum, debile, diadema, teres* and the *Thalassiosira* species, extend pretty far south, at any rate as far as the North Sea and the Skagerak; others, such as *Thalassiosira hyalina, Chætoceras furcel-*

latum and *Mitra,* are exclusively arctic, the first two being found only in the winter on the Norwegian coast from Stadt northwards.

It is a remarkable fact that so many of the plankton forms that are distributed along the arctic shores, are found in and upon the ice in the form of spores. The contents of many of these are in so good a state of preservation, that in all probability they were alive when found. The formation of spores is such a general process among the neritic diatoms, that it must be important for the existence of the algæ. As I have pointed out in another work, (*Hjort* and *Gran* [99]), it is probable that these algæ exist, during the time that they are not found in the plankton, as spores. On more southern shores, they can only pass their period of rest at the bottom of the sea in the shallower places. In the Polar Sea, the spores may attach themselves to the ice-floes, and be frozen into them. The possibility of their retaining their power of germinating while drifting with the ice-floe, and again developing when they are brought into more favourable conditions, is not excluded.

In the Polar Sea itself, these species do not appear to occur as plankton; but on the east coast of Greenland they are all found again in the summer (cfr. Gran [97, 3]), often in great quantities. It is probable that they may develope from the spores that are found in the melting drift-ice; but it is also not impossible that they originate from the nearest coast. Even if the plankton flora that comes to life every summer on the east coast of Greenland is not periodically replenished by spores from the drift-ice, it is still probable that it is due to these spores that the plankton flora on the north coast of Siberia is so similar to that of the coasts of Greenland.

(2) *Species that are found living both in plankton and on ice.*

To this category belong all the species that occur in the greatest quantities on the ice-floes. *Melosira hyperborea, Nitzschia frigida, Fragilaria oceanica, Fr. cylindrus* are the prevailing species; they are all also found as plankton. *Nitzschia* generally occurs rather sparsely in the plankton, but the others may predominate. They all have a rather wide distribution, but they only occur in cold seas, and especially between ice-floes, or where the sea is covered with ice.

Upon the polar ice they live and multiply during the summer. In many cases, the cell-contents are in a good state of preservation; and the observations as to colour, etc. that *Nansen* and *Blessing* made during the expedition, also prove that the algæ were alive. In these species too, spores are to some extent known; in *Fragilaria oceanica* they have already been described by *Cleve* [73]; in *Melosira hyperborea* they have been up to the present unknown, but were found in considerable quantities in several of the Nansen expedition samples (*vide* p. 53).

To this class belong the following species:

Navicula septentrionalis,
— *gelida,*
Fragilaria oceanica,
— *cylindrus,*
Nitzschia frigida,
— *lævissima,*
— *acicularis,*
Chætoceras septentrionale,
Melosira hyperborea.

Most of these species were found wherever diatom-samples were collected upon the drift-ice. They form a biological community, which seems to exist wherever the conditions are favourable for their existence. Their occurrence cannot therefore throw any light upon the origin of the ice-floes where they live.

(3) *Species that are known from ice-floes only, or also as littoral forms.*

To this class belong most of the forms that occur. They are not found in particularly large numbers, but yet evenly distributed among most of the samples. A few of the samples may have more of them, others again fewer. In the samples taken from ponds of fresh water on the ice-floes, some predominate at the expense of the others; but they are, in the main, the same species that are found in all the samples. The preserved specimens of these species also, for the most part, still have their cell-contents, so that it is evident they were alive.

How these species have come upon the ice has not yet been clearly determined; but it is highly probable that they congregated upon the under surface of the ice somewhere near the land, in the manner observed by Vanhöffen in the Karajak Fjord. Most of these species are organisms with the power of self-motion; a few, such as the discoid forms, are not, indeed, actively motile, but they can probably ascend towards the light by the aid of air-bladders in or outside the cells. It is at any rate certain that these are also found *alive* on the under surface of the ice. The diatom samples from the west side of Novaya Semlya, examined by *Grunow*, were also found on the *under surface* of an ice-floe. They were evidently alive also, as there were many small and thin-walled forms among them, which otherwise could hardly have been preserved. It is, moreover, a phenomenon with which most arctic voyagers are acquainted, that the drift-ice is sometimes quite brown on the under surface (with living diatoms)[1]; when the ice has been turned upside down, the brown colour is visible from a great distance.

Some of those diatoms that are still upon the ice when autumn arrives, will possibly sink to the bottom, but others will certainly be frozen into the ice. Nansen, as already mentioned, observed that the ice in autumn is sometimes full of plankton forms that have been frozen in. If there are diatoms upon the under surface of the ice, these will also be frozen in when the ice increases in thickness[2]. The large masses that both Hartz and Nansen found, sometimes frozen into the ice, sometimes living at the bottom of the ponds on the surface of the ice, can only be formed of a thick community of diatoms, *that have been living on the ice.*

When the diatoms are frozen in, most of them will probably perish, but some of them, protected by the masses of mucilage, will probably be able to keep alive, so as to be capable of developing when the ice melts and the conditions for living are once more favorable. By the melting of the surface-

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[1] In 1892, I found that ice that was quite new, *perhaps not more than a week old,* was sometimes quite red-brown on the under surface; and it appeared under the microscope that this was algæ. It is affirmed that the seal shows a preference for being on such ice, perhaps because there are many crustaceans in the water, that live upon the algæ plankton. *F. N.*

[2] I often observed brown stripes and thin layers in the ice, which could only be formed by the diatoms having actually lived on the under surface of the ice, and having been frozen in. *F. N.*

ice, these diatoms are set free in the fresh-water ponds on the floes, and then begin to develope and form communities at the bottom of these ponds.

The authors who have previously discussed the subject of the diatom-flora of ice-floes, appear to start with the assumption that the diatoms have come on to the ice quite by chance, like the inorganic ooze and remains of fresh-water organisms that are found in similar circumstances. But if this were the case, the various samples would differ in their composition. Experience shows, however, that the same species, though varying in number, are found in all the samples, and that they are the same species that were found at Cape Wankarema and on the east coast of Greenland. This similarity can only be explained by the assumption that it is a certain community, that has lived, at any rate for a time, on the ice. Most of the species, moreover, are found in such large numbers, that on that account alone, it must be assumed that they have lived and multiplied on the ice.

In addition to this ice-flora, however, there are also a few specimens of other species that may have found their way on to the ice by chance. These are especially the fresh-water forms, which will be briefly described hereafter.

Can any conclusions be drawn from the composition of the ice-flora, as to the origin of the ice?

This question cannot be answered decisively, until further investigations have been made of the diatoms of the ice; but the results hitherto obtained indicate that in many cases the study of diatoms will prove of valuable assistance in studying the drift of the ice.

The first attempt in this direction was made by Nansen, whose diatoms from ice-floes on the east coast of Greenland were examined by *Cleve*. These diatoms were so similar to the samples collected at Cape Wankarema during the Vega Expedition, that Cleve considered it probable that the East Greenland ice-floes must have drifted with the ocean currents from some place or other in the neighhourhood of Cape Wankarema. This correspondence between the ice-diatoms on the east coast of Greenland and at Cape Wankarema, was one of the probabilities upon which Nansen built, when he put forward his theory of a continuous current across the Polar Sea from Siberia to East Greenland.

When Östrup subsequently examined the ice-diatoms collected on the east coast of Greenland during the Ryder Expedition, he found, it is true, in

these samples, all the species and varieties that were characteristic of the collections from Cape Wankarema; but he did not venture to draw any conclusions as to a direct connection between the ice-flora at the two places; for he found in the Greenland collection 3 small species that appeared in comparatively large numbers, and which Cleve had not mentioned as coming from Cape Wankarema, viz. *Navicula Hartzii,* Oestr., *Navicula (Pinnularia) perlucens,* Oestr., and *Chætoceras septentrionale,* Oestr. There were also several forms which occurred, indeed, both on the east coast of Greenland and at Cape Wankarema, but which Östrup had no opportunity of identifying, as Cleve's drawings and descriptions were altogether inadequate, and the preparations published by Cleve and Möller were not accessible to him.

In 1896, Cleve was again able to demonstrate the great similarity between the ice-flora at Cape Wankarema, and the ice-diatoms that he found floating freely among the plankton at Cape Eglinton. By an examination of the original prepared specimens, he was able to correct some of Östrup's determinations, and show that what Östrup had collected had also the greatest possible resemblance to the Cape Wankarema samples.

But while so little is known concerning the distribution of ice-diatoms, it is possible to believe that the ice-flora may be uniform upon all the shores of the Polar Sea, like the neritic plankton flora. In other words, it is possible that the correspondence between the Siberian and the Greenland samples is due to the circumstance that the biological conditions were the same in both places. There are undoubtedly species that are distributed over the entire Polar Sea, especially such species as occur both as plankton and on the ice, like the above-mentioned *Nitzschia frigida, Melosira hyperborea, Fragilaria oceanica, Fr. cylindrus,* etc.

The facts hitherto obtained seem, however, to indicate that the ice-flora in other parts of the Polar Sea that are not in direct communication with the current from North Siberia to East Greenland, is essentially different from the algæ-community, which may be best designated the *Wankarema community.* The sample from the sea west of Novaya Semlya, examined by Grunow, and Vanhöffen's collection from the Karajak Fjord, agree with one another and with the Wankarema samples in those species that live all over the Polar Sea under similar conditions; but the characteristic Wankarema forms are missing,

and instead of them there are a few special forms. The same may be said of the sample from the Barents Sea, examined by Cleve, which, in addition to the ice-flora, contains some fresh-water forms which will be briefly described later on.

The composition of the samples under discussion strengthens the probability of Nansen and Cleve's theory that the diatoms in North Siberia and East Greenland are directly connected with one another. The samples taken while the 'Fram' was drifting across the Polar Sea, contain almost exactly the same species that Cleve found at Cape Wankarema and Cape Eglinton, and that Östrup has pointed out from East Greenland. The peculiarly Greenland forms, *Navicula Hartzii* and *N. perlucens*, however, are missing. On the other hand, the sample that Nansen took in the Barents Sea on an ice-floe which, he supposed, had no connection with the polar current, has none of the Wankarema forms, and contains, besides some fresh-water forms and a few of the commonest ice forms, hardly any but the one species, *Coscinodiscus polyacanthus*, but this, it is true, in immense quantities,

In the following table, I have brought together all the species that are found in Nansen's samples, and which are only known from ice, or as littoral forms. The various species are placed in eight vertical columns, according to the locality in which they were found, viz.

1. Polar Sea, in lat. 81° N. and long. 125—127° E. **N.** 2. Wankarema (Kjellman—Cleve). **W.** 3. East Greenland (Östrup). **R.** 4. Cape Eglinton (Cleve). **E.**	Supposed to be connected with the drift-ice across the Polar Sea.
5. W. of Novaya Semlya (Grunow). **G.** 6. Karajak Fjord, West Greenland (Vanhöffen). **K.** 7. Barents Sea, Jackson (Cleve). **J.** 8. Barents Sea, Nansen. **N.**	Probably local ice-formations, which are not carried with the great polar current.

The species that are littoral, or found in bottom-samples as well as on the ice, are indicated by an asterisk. As earlier naturalists have not always

distinguished between dead cell-walls and living organisms, some of their statements are of little value. The valves found in the Arctic Ocean and the North Atlantic, may easily have come from species that have lived on the drift-ice.

	N.	W.	R.	E.	G.	K.	J.	N.
	Arctic Ocean Nansen	Wankarema Kjellman-Cleve	East Greenland Ryder-Östrup	Cape Eglinton Cleve.	Novaya Semlya Grunow	Karajak Fjord Vanhöffen	Barents Sea Jackson-Cleve	Barents Sea Nansen
Amphiprora paludosa v. *punctulata*	+	+	+	+	+			
— *Kjellmanii*	+	+		+			+	
— — var. *glacialis*	+		+	+	+			
— — „ *striolata*	+		+					
— — „ *kryophila*	+	+	+	+				
* — *gigantea* v. *septentrionalis*	+	+	+	+				
* *Tropidoneis maxima* v. *dubia*	+							
Pleurosigma Clevei v. *sibirica*	+	+		+				
* — *Stuxbergii*	+	+	+	+	+	+		
— — v. *rhomboides*	+	+	+					
Caloneis kryophila	+	+	+				+	
* *Diploneis didyma*	+		+					
— *litoralis* v. *arctica*	+	+	+	+			+	
* — *Smithii*	+		+					
Navicula lineola	+				+			
— *Oestrupi*	+		+	+				
— *kryokomites*	+	+	+	+				+
* — *Spicula*	+	+	+					
* — *vitrea*	+	+	+	+				
— *Kjellmanii*	+	+	+	+				
Stenoneis inconspicua v. *Baculus*	+	+	+	+				
* *Navicula subinflata*	+	+	+	+			+	
— *pellucida*	+	+	+					
* *Gomphonema exiguum* v. *pachyclada*	+	+	+	+				
— — v. *arctica*	+	+	+	+				
— *kamtschaticum* v. *grœnlandica*	+	+	+	+				
Navicula valida	+	+	+	+			+	
— *transitans*	+	+	+	+		+	+	
— v. *incudiformis*	+	+	+					
* — *directa*	+	+	+	+		+		

	N.	W.	R.	E.	G.	K.	J.	N.
	Arctic Ocean Nansen.	Wankarema Kjellman-Cleve	East Greenland Ryder-Östrup	Cape Eglinton Cleve	Novaya Semlya Grunow	Karajak Fjord Vanhöffen	Barents Sea Jackson-Cleve	Barents Sea Nansen
* *Navicula directa* v. *subtilis*	+	+	+	+				
— — v. *remota*	+		+					
— *gelida*	+	+	+		+			
— *derasa*	+	+	+	+				
— — v. *erosa*	+	+	+	+				
— *detersa*	+	+	+		+			
— *Blessingii*	+		?					
— *trigonocephala*	+	+	+	+				
— *recurvata*	+							
— *sibirica*	+	+	+	+				
— *superba*	+	+	+	+				
— — *subacuta*	+							
— — *elliptica*	+	+	+					
— — *crassa*	+		+					
— *obtusa*	+	+	+	+				
— *algida*	+	+	+	+	+		+	
* — *glacialis*	+		+					
* — *pygmæa*	+							
Pinnularia perlucens			+					+
* — *ambigua*	+	+	+	+				
* — *quadratarea*	+	+	+	+				
— — v. *Stuxbergii*	+	+	+	+	+		+	
— — v. *bicontracta*	+		+	+				
— — v. *constricta*	+		+	+				
— *semiinflata*	+		+					
— — v. *decipiens*	+	+	+	+				
— — v. *inæqualis*	+		+					
* *Amphora lævis* v. *lævissima*	+		+	+				
Surirella Oestrupi	+		+					+
Hantschia Weyprechtii	+		+		+			
* *Nitzschia hybrida*	+	+	+	+	+	+		
* — *distans*	+	+		+				
— *Brebissonii* v. *borealis*	+	+	+	+				
— *gelida*	+	+	+					
— *polaris*	+	+	+	+	+			
— *lanceolata* v. *pygmæa*	+	+	+	+				
* — *Closterium*	+							

	N.	W.	R.	E.	G.	K.	J.	N.
	Arctic Ocean Nansen	Wankarema Kjellman-Cleve	East Greenland Ryder-Östrup	Cape Eglinton Cleve	Novaya Semlya Grunow	Karajak Fjord Vanhöffen	Barents Sea Jackson-Cleve	Barents Sea Nansen
Xanthiopyxis polaris	+							
Actinocyclus alienus v. *arctica* .	+	+	+	+				
Coscinodiscus polyacanthus . . .	+	+	+	+				+
— *curvatulus*	+	+	+	+	+		+	
— *Kützingii* v. *glacialis* . .	+							
— *bioculatus*	+	+		+	+			
— *septentrionalis*	+		+					

It will be immediately seen from the table, that the first four columns have almost all their species in common, while the last four have only a very small number of these typical Wankarema forms.

In the accompanying map, (fig. 1, p. 21), the places are marked where ice-diatoms have hitherto been found; the stations where the Wankarema community was found are indicated by a black circular spot, the others by a circle. N indicates the samples collected by Nansen, R, Ryder's collections, and G, Grunow's samples from Novaya Semlya.

Both the table and the map go to show the possibility of ice-diatoms being employed as an assistance in investigating the currents and the drift of the ice in the Polar Sea; but many investigations will be required before perfect certainty can be arrived at.

4. *Fresh-water forms.*

Fresh-water forms play a very unimportant part in the samples from the Polar Sea. I have found only a few species, all of them in very small numbers, most of them represented by only a single specimen. I have not, therefore, been able to determine whether they have had cell-contents; they have probably not been living on the ice, or they would have multiplied. The species that occur have such a wide distribution, that no conclusions can be drawn from their occurrence.

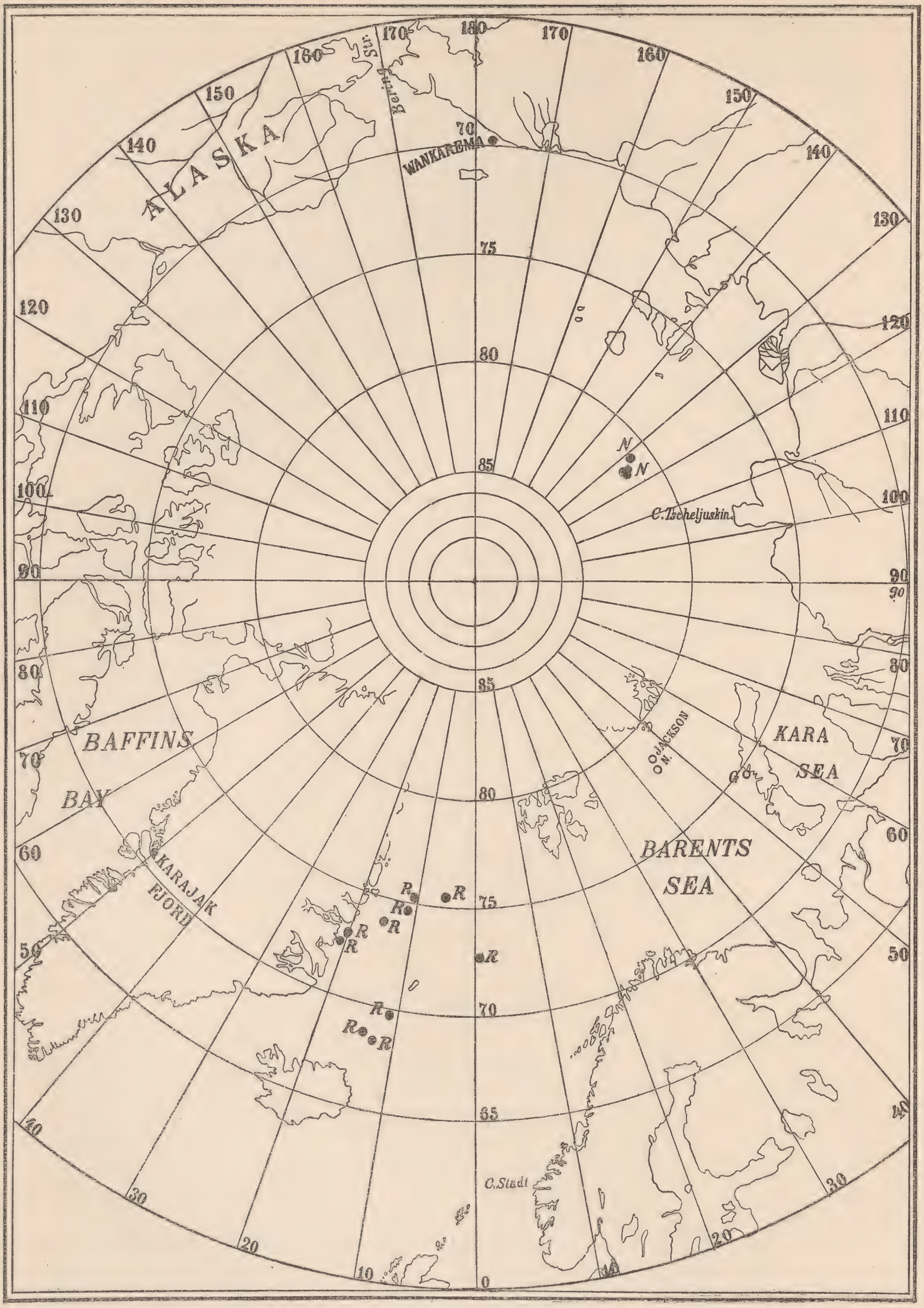
ALASKA
Behring Str.
WANKAREMA
C. Tscheljuskin
BAFFINS
BAY
KARAJAK
FJORD
BARENTS
SEA
KARA
SEA
JACKSON
I.
C. Stadt
N
N
R
R
R
R
R
R
R
R
R
R
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
75
80
85
65

Fig. 1.

I have found the following species:

Cymbella cuspidata,
Navicula rhynchocephala,
Pinnularia borealis,
Fragilaria Harrisonii,
Nitzschia denticula,
Melosira crenulata.

The sample taken by Nansen from the Barents Sea contains comparatively more fresh-water forms than the others, *Melosira crenulata* occurring rather plentifully.

The sample that Cleve has examined from the Barents Sea contains more fresh-water than salt-water forms, *Melosira crenulata* being common. Cleve infers from this that the ice has probably been formed in the neighbourhood of a river; but it is impossible to base any decisive conclusions upon the fresh-water diatoms.

Östrup's collection also contains a far greater number of fresh-water forms than the one under discussion. Östrup and Hartz suppose that the diatom valves have been carried on to the ice from the land by the wind.

SYSTEMATIC LIST OF THE SPECIES.

In the systematic arrangement of the naviculoid diatoms, I have followed Cleve's Synopsis. Cleve has rendered great service by giving in this work a survey of all known species. His system, indeed, appears to me to be somewhat one-sided, as he has made too much use of certain features for separating his main groups, especially of the striation of the valves; but at present it is scarcely possible to draw up a system that answers better to the genetic connection of the forms. For this purpose a more thorough knowledge is required of the structure of the entire cell, and the actual conformation of the cell-walls. The investigations of recent years, especially those of Otto Müller, have shown that the structure in the various forms may be so diversified that the terms generally used — "striæ", "punctæ", "areolæ" — give only a very inadequate idea of the actual circumstances. The form of the raphe must above all be taken into consideration in the division into large groups.

One fault in the form of Cleve's system is that sections with separate generic names, such as *Diploneis, Gyrosigma,* etc., are ranged side by side with others that are only entered as *Naviculæ fusiformes, orthostichæ,* etc. This gives the impression that Cleve looks upon all sections as equally good genera; but he has not wanted to give too many new generic names at the present stage of investigation. In other words he considers even his own classification as temporary.

The collection before us is a very limited one, a special feature being that it contains only a very small number of the large main groups, while some of these, e. g. *Naviculæ lineolatæ,* are represented in tolerable abun-

dance. I have therefore been desirous of not giving expression to my own personal views by departing from the order of Cleve's Synopsis, the more so as from practical considerations, this vade-mecum of all students of diatoms should be followed as far as possible.

In other respects, the classification in Van Heurck's 'Traité des Diatomées' is followed. With regard to the designation of the morphological axes and the various parts of the cell, I have kept entirely to Otto Müller's [95] excellent system.

I. *PENNATÆ.*

A. RAPHIDEÆ.

AMPHIPRORA, (Ehb.) Cl.

1. *Amphiprora paludosa,* W. Sm. [53].
   Var. *punctulata,* Grun. [80] p. 62, Pl. IV, fig. 84.
   Grun. [84] p. 105, Pl. A, figs. 54, 55.
   Cl. Syn. I, p. 15.

Rather frequent, especially in masses in open channels.

Geographical Distribution. Cape Wankarema, Kara Sea, on the under surface of a piece of ice near Novaya Semlya, 74° 48′ 4″ N. Lat., 54° 52′ 8″ E. Long, Aug. 2, 1872 (Grunow [84] p. 105). On ice off the east coast of Greenland, and in latitude 72° 46′ N., longitude 0° 13′ E. (Östrup [95] p. 443). Floating freely off Cape Eglinton (Cleve [96] p. 14).

2. *Amphiprora Kjellmanii,* Cl. [80], pp. 15, 61, Pl. IV, fig. 83. Cl. Syn. I, p. 16.

The forms allied to this species are little known as yet, as they generally occur in small numbers, and as their cell-walls are so slightly silicated, that an opportunity is seldom afforded of observing entire cells. In the samples from the Polar Sea, I have been able to distinguish the following forms:

Var. *glacialis*, Cl. [83] p. 477, Pl. 35, fig. 12.

with f. *subtilis*, (Grun.) *A. kariana* v. *subtilis*, Grun. [84] p. 105, Pl. A, figs. 52, 53.

Dimensions. a = 29—62 μ, striæ, 13 or 14 per 10 μ[1].

Var. *striolata*, (Grun.) [80] p. 62, Pl. IV, fig. 81. *A. striolata*, Grun. l. c.

Var. *genuina*.

Dimensions. a = 90—168 μ, striæ on the keel, 11—13·5 per 10 μ.

Var. *kryophila*, Cl. [83] p. 477, Pl. 35, fig. 11. *A. kryophila* Cl. l. c.

Striæ about as close on the keel as on the valve, 13—16 per 10 μ.

Scarce in most of the samples, v. *glacialis* found especially in open channels, v. *kryophila* in pools on the ice.

Geographical Distribution. Arctic waters — Kara, Wankarema, East Greenland.

3. *Amphiprora gigantea*, Grun. [60] p. 568, Pl. IV, fig. 12.

Var. *septentrionalis*, (Grun.) [80] p. 63, Pl. V, fig. 87. Cl. Syn. I, p. 18. *A. decussata* v. *septentrionalis*, Grun. l. c. Östrup [95] p. 444, Pl. VII, fig. 79.

Scarce.

Geographical Distribution. Arctic waters — Finmark, Wankarema, East Greenland.

TROPIDONEIS, Cl.

4. *Tropidoneis maxima*, (Greg.) Cl. *Amphiprora maxima*, Greg. [57] p. 507, Pl. XII, figs. 61 & 61 b.

Var. *dubia*, Cl. & Grun. [80] p. 65, Pl. V, fig. 89. Cl. Syn. I, p. 26.

Dimensions. a = up to 120 μ, t = 12 μ, striæ, 17 per 10 μ.

Scarce.

Geographical Distribution. Finmark, 'nicht selten' (Cl. & Grun.).

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[1] a = the apical axis, t = transapical axis, p = pervalvar axis. Cf. Otto Müller [95].

PLEUROSIGMA, W. Sm.

5. *Pleurosigma Clevei*, Grun. [80] p. 52, Pl. III, fig. 70 a, b.
Var. *sibirica*, Grun. in Cl. Syn. I, p. 37.
Rare.
Geographical Distribution. Wankarema, Cape Eglinton.

6. *Pleurosigma Stuxbergii*, Cl. & Grun. [80], p. 54, Pl. IV, fig. 74. Cl. Syn. I. p. 41.
Singly in most of the samples.
Geographical Distribution. Arctic waters — Kara, Wankarema, Franz Josef Land, East Greenland.

Var. *rhomboides.* Cl. Syn. I, p. 41.
P. rhomboides, Cl. [80] pp. 14, 54, Pl. IV, fig. 73.
Together with the chief species, but less frequent.
Geographical Distribution. Arctic waters — Kara, Wankarema, East Greenland.

CALONEIS, Cl.

7. *Caloneis* (?) *kryophila.* Cl. Syn. I, p. 64.
Navicula kryophila, Cl. [83] p. 473, Pl. 37, fig. 43.

Fairly plentiful in some of the samples, especially on the ice-foot. Size. a = 36—62 μ, t = 18—24 μ, striæ 8—10 per 10 μ. Cleve's doubt, when he refers this species to *Caloneis*, appears to me to be well founded. In my opinion, it is more closely connected with *Pinnularia quadratarea*, A. Schm.

Distribution. Arctic waters — North Siberia, Wankarema, East Greenland, West Greenland (Östrup [97]).

DIPLONEIS, Ehb.

8. *Diploneis didyma*, Ehb. [40], p. 75. Cl. Syn. I, p. 90.
Singly.
Distribution. Cosmopolitan.

9. *Diploneis litoralis* (Donk). Cl. Syn. I, p. 94.

Navicula litoralis, Donk [70], p. 5, Pl. I, fig. 2.

Occurs not infrequently in most of the samples, in various forms. The size varies considerably; a = 22—63 μ, t = 12—26 μ, $\frac{a}{t}$ = 1·9—4·0. Striæ, 12—16 per 10 μ. The most frequent forms are those of the following dimensions: a = 30—55 μ, t = 14—17 μ, $\frac{a}{t}$ = c. 2·5; striæ, 15 or 16 per 10 μ. These forms are thus most nearly related to var. *arctica,* Cl. [96], p. 18, Pl. I, fig. 7.

Distribution. Almost cosmopolitan; var. *arctica,* however, only in the Polar Sea (North Siberia, E. Greenland).

10. *Diploneis Smithii* (Bréb.). Cl. Syn. I, p. 96.

Navicula Smithii, Bréb. in W. Smith [56], p. 52.

Singly.

Distribution. Cosmopolitan in salt and brackish water.

NAVICULÆ FUSIFORMES, Cl.

11. *Navicula lineola,* Grun. [84], p. 104, Pl. A, figs. 45, 46. Cl. Syn. I, p. 107,

Scarce.

Distribution. Franz Josef Land.

12. *Navicula Oestrupi,* Cl. [96, 1], p. 20, Pl. I, fig. 10. *Amphiprora amphoroides,* Oestr. [95], p. 442, Pl. VI, fig. 70.

Scarce.

Distribution. East Greenland and Cape Eglinton, on ice.

NAVICULÆ ORTHOSTICHÆ, Cl.

13. *Navicula kryokonites,* Cl. [83], p. 473, Pl. 37, fig. 44. Cl. Syn. I, p. 109.

Pl. III, fig. 9.

Not uncommon, especially small forms (a = 25—41 μ, t = 6—9 μ).

Distribution. Wankarema, East Greenland.

14. *Navicula Spicula* (Hickie) [73], p. 290. Cl. Syn. I, p. 110.

Stauroneis Spicula, Hickie, l. c.

Not uncommon. Dimensions, a = 80—105 μ, t = 11 or 12 μ.

Distribution. Arctic America, Wankarema, Kara Sea, East Greenland, Northern Europe.

15. *Navicula vitrea,* Cl. Syn. I, p. 111.

Pleurosigma vitreum, Cl. [80], p. 15, Pl. IV, fig. 78.

Scarce.

Distribution. Arctic waters, Adria.

16. *Navicula Kjellmanii,* Cl. Syn. I, p. 111.

Pleurosigma Kjellmanii, Cl. [80], p. 14, Pl. IV, fig. 80.

Navicula Vegæ, Cl. [83], p. 474. Östr. [95], p. 439.

Scarce.

Distribution. Arctic waters — North Siberia, Kara, Wankarema, E. Greenland, on ice.

STENONEIS, Cl.

17. *Stenoneis inconspicua* (Greg.) Cl. var. *Baculus* Cl. Syn. I, p. 124.

Navicula Baculus, Cl. [83], p. 474, Pl. 37, fig. 51.

Not uncommon. Dimensions, a = 54—92 μ, t = 10 or 11 μ, Striæ, 18 per 10 μ.

Distribution. North Siberia, Wankarema, East Greenland, upon ice.

NAVICULÆ DECIPIENTES, Grun.

18. *Navicula subinflata,* Grun. in Cleve [83], p. 470, Pl. 37, fig. 50. Cl. Syn. I, p. 141.

Pl. II, figs. 16, 17.

Common, especially in pools on the ice.

Distribution. Arctic America, Wankarema, Greenland, Norway.

NAVICULÆ MICROSTIGMATICÆ, Cl.

19. *Navicula pellucida*, Cl. Syn. I, p. 144.

Stauroneis pellucida, Cl. [83], p. 475, Pl. 35, fig. 10.

Scarce.

Distribution. Wankarema, North Siberia, E. Greenland, on ice (Östrup).

20. *Navicula septentrionalis*, Östrup [95], p. 439, Pl. VIII, fig. 97. Cl. [96, 1], p. 11.

Not uncommon.

Distribution. Arctic Ocean, on ice, and on the coasts as plankton; Baffin's Bay, Karajak Fjord, E. Greenland.

CYMBELLA, Ag.

21. *Cymbella cuspidata*, Kütz. [44], p. 79, Pl. 3, fig. XL. Cl. Syn. I, p. 166.

Singly.

Distribution. Fresh water, circumpolar, especially in cold and temperate climates.

GOMPHONEMA, Ag.

22. *Gomphonema exiguum*, Kütz. [44], p. 84, Pl. 30, fig. 58. Cl. Syn. I, p. 188.

Var. *pachyclada*, Bréb. [38], p. 21. *G. pachycladum*, Bréb. l. c.

G. septentrionale, Oestr. [95], p. 414, Pl. III, figs. 9, 10.

Pl. II, figs. 18, 19.

Distribution. Shores of the Arctic Ocean — Wankarema, Bering Strait, E. Greenland; Normandy.

Var. *arctica* (Grun.) in V. H. Syn. Pl. XXV, figs. 31, 32.

G. arcticum, Grun. l. c. Grun. [84] p. 102, Pl. A, fig. 12.

Distribution. Shores of the Arctic Ocean — Franz Josef Land, Novaya Semlya, Wankarema, E. Greenland.

Both the varieties occur pretty frequently in most of the samples; var. *arctica* is the commonest. The valves are always asymmetrical in relation

to the apical axis; the raphe lies almost entirely on one side of the mid-rib. The striæ extend on one side right up to the rib; but on the other side, where the raphe lies, there is a more or less distinct, unstriated region between the raphe and the striæ, a unilateral axial area.

Dimensions. Var. *pachyclada* — a = 22—40, t = 6·5—8·5, striæ, 10—12 per 10 μ.

— *arctica* — a = 25—36, t = 6·5—8, striæ, 14—17 per 10 μ.

23. *Gomphonema kamtschaticum*, Grun. [78], p. 109, Pl. III, fig. 4. Cl. Syn. I, p. 188. Cl. [96, 1], p. 19.

var. *grœnlandica* (Oestr.).

G. grœnlandicum, Oestr. [95], p. 414, Pl. III, figs. 8, 11, 12. Pl. II, figs. 20, 21.

Common in most of the samples. This species also is always asymmetrical in relation to the apical axis, in the same manner as the preceding one, as Östrup also states.

Distribution. Wankarema, E. Greenland, upon ice.

NAVICULÆ LINEOLATÆ, Cl.

This group is abundantly represented in the polar ice. The species are to some extent very difficult to distinguish, as they vary to an extraordinary degree. Cleve, in his paper on the diatoms of the Vega Expedition [83], draws attention to the fact that on the ice-floes off Cape Wankarema, a number of forms were found that were nearly related to *Navicula directa*, but which differed so greatly from one another, that they might all have been considered good species, if every possible transition-form had not been found in the same samples. These forms differ from one another in the contour of the valves, and the closeness and direction of the striæ. In some forms the striæ are interrupted, in others they are entire; some are quite symmetrical in relation to the apical plane, when the usual curve of the mid-rib at the ends of the valve is left out of consideration; others are more or less asymmetrical. Some have almost flat valves, while in others they are curved as in *Achnanthes*. The latter species should belong to the genus *Rhoiconeis*,

established by Grunow; but as, on the other hand, they are so nearly related to the regular forms of *Navicula Lineolatæ*, the genus *Rhoiconeis* cannot be retained. Cleve, in his above-mentioned paper [83], has arranged these difficult forms with delicate systematic discernment.

Östrup [95] has found the same series of forms in some samples collected by the Ryder Expedition on ice-floes off the east coast of Greenland and as far east as 72° 46′ N. Lat. and 0° 13′ E. Long. Östrup follows Cleve's classification, and also describes some peculiar forms.

Subsequently, Cleve also found these species off the east coast of Greenland, where they were drifting in small quantities among the plankton, 30 nautical miles to the east of Cape Eglinton. In his report of this [96, 1] and in his Synopsis, Cleve principally follows the same classification as before, although by placing several of the former species as varieties of others, he has considerably reduced their number.

In the samples collected by Nansen, this very series of species also belongs to the characteristic forms; all the variations described by Cleve and Östrup are also found there. I shall here try to give a systematic survey of them.

The valves in all these species are provided with a narrow median rib. It widens in the middle, sometimes rather unilaterally, into a central node; and at the ends it is bent into a hook, which lies in the valvular plane. Both ends are bent to the same side of the apical plane.

As a rule, only the two central pores of *the raphe* are visible; the rest is so narrow that it vanishes in the median rib. In a few of the forms, the central pores are very close together, only separated by a cylindrical isthmus (e. g. *Navicula detersa*), in others they may be rather farther apart. In the latter case, they are bent a little outwards, both to the same side as the ends of the median rib. The course of the raphe may be best followed in fragments. In certain species, it divides the median rib into two almost symmetrical halves; in others it lies almost entirely on one side of the rib, and always on the side towards which the ends of the rib curve. This is often the case in *Navicula valida*, and to a still greater extent in the above-mentioned species, *Gomphonema kamtschaticum* var. *grœnlandica*, which does not, however, belong to this group of forms.

The striation of the valves is closely connected with the course of the raphe. The striation is due to the strengthening interiorly of the cell-wall

by ribs. Between the ribs there are grooves of the same width as the ribs, and closed outwards with a very thin membrane. Inwards, towards the inner chamber of the cell, they are probably open; but this I have not been able to decide with certainty.

In cases where the raphe lies in the middle of the median rib, the grooves run right up to the latter; but in the middle, where the valve will not bear any weakening, on account of the large central pores, they do not reach quite up. In this way, a larger or smaller *central area* is formed.

When the course of the raphe is not median, it is bounded by a strong rib only on one side; on the other side the margin is much thinner, and in the most asymmetrical forms, the cell-wall here may be quite without anything to strengthen it. The grooves then run right up to the rib on one side; but on the other, they do not reach so far. An axial area is left, which, however, is generally rather narrow. If the grooves were to run right up to the raphe on this side where the margin is already so weak, the wall would probably not have the necessary strength.

The striæ may also be interrupted in one place or several places between the median rib and the margin of the valve, as well as in the centre and along the raphe. Most frequently there is only one, rather large interruption, which occurs in all the striæ on the same side, with the exception of the outermost, which is quite short. This then, in agreement with Cleve, I consider to be the *lateral area*. In symmetrical forms which, like *Navicula detersa* and *derasa*, have no axial area, there is a lateral area on each side of the median rib. In asymmetrical forms such as *Navicula transitans* var. *incudiformis*, there is a lateral area only on the side of the median rib where the raphe and the axial area are not found.

Other forms, such as *Navicula trigonocephala*, have their striæ divided into several portions.

The unstriated areas of the cell-wall are thicker than the membranes that close the grooves at their outer extremity; but they are somewhat thinner than the transverse ribs that separate the grooves.

The system of grooves and ribs, which forms the striation, has a twofold biological significance. The membrane must be strengthened for mechanical reasons, and when the material is limited, a greater firmness can be attained by a strong network than by an even thickening of the cell-wall.

On the other hand, an even thickening would check the osmotic connection with the outside world, whereas diffusion is not essentially hindered if only a part of the wall remains unthickened.

Very thin-walled diatom cells generally have a very fine and inconspicuous striation. Apart from a few spores, on the other hand, no instances are known of thick, highly silicified walls that have not a strong and distinct system of ribs or network, at any rate on part of the cell-wall. The curved forms of this group are very interesting, in as much as their two valves differ from one another in structure. The one valve, which is curved outwards, has a strong system of ribs, occupying nearly the entire surface of the valve; while the other, which curves inwards towards the interior of the cell, has its striæ broken by a large lateral area (*Navicula superba*, etc.), or, as in the symmetrical forms, by two such, one on each side of the median rib *(N. recurvata)*. This also indicates that the rib system generally occurs where the greatest strengthening is required.

It is difficult to decide which of the characteristics in this group are to have the greatest importance attached to them. The dimensions vary extremely here as in all diatoms, and with them the outward form also varies. In the series of developments that each species goes through from one auxospore formation to another, there are already great variations in size. These variations have therefore no systematic significance whatever. In elongated forms, it is especially the length of the apical axis (a), that is subject to such variations, while the transapical axis (t) is far more constant. The proportion a : t is therefore also very variable. The striæ also vary to a certain extent with the size, the larger forms always having a somewhat coarser striation than the smaller developmental forms of the same species. Among these species also, however, there are probably variations in size, that really have a systematic significance; but as long as living subjects are unobtainable, in which the development may be followed, no decisive results can be arrived at. In many particulars, therefore, it must depend upon the subjective judgement, how much consideration is to be paid to the various characters.

In his last treatise (Synopsis II, p. 10, seq.), *Cleve*, in my opinion, has attached too little importance to symmetrical proportions; but in other respects, my detailed investigations and numerous measurements have led me to the

conviction that Cleve's grouping in species and varieties is in the main the most natural that can be made at present.

I have succeeded in distinguishing the following forms:

I. Fresh-water forms:

24. *Navicula rhynchocephala,* Kütz. [44], Pl. 30, fig. 35. Cl. Syn. II, p. 15.

One specimen.

Distribution. In fresh water, circumpolar.

II. Salt-water forms:

A. Valves uniform in construction, almost flat, with only a low curvature at the margin.

25. *Navicula valida,* Cl. & Grun. [80], p. 32, Pl. II, fig. 29. Cl. Syn. II, p. 25. Pl. I, figs. 11, 12.

Valves flat, broadly lanceolate; a = 50—131 μ, t = 18—31 μ, striæ, 6—8 per 10 μ. Very unsymmetrical; the raphe lies almost entirely on one side of the median rib, the central pores rather far apart. The unilateral axial area very conspicuous.

The f. *minuta,* described by Cleve [83], p. 466, is also in Nansen's samples.

Not uncommon.

Distribution. Polar Sea — Kara, Wankarema, East Greenland.

26. *Navicula transitans,* Cl. [83], p. 467, Pl. 36, fig. 31. Cl. Syn. II, p. 27. Pl. I, figs. 4, 5.

A very variable species, closely allied to the broadest forms of *N. directa.* Valves lanceolate; $\frac{a}{t} = 4—6$. The typical form is conspicuously asymmetrical, with central pores rather far apart, and a distinct, unilateral axial area. The striæ are continuous and rather coarse. The following forms of the principal species may be distinguished:

f. *genuina;* a = 56—86 μ, t = 15—19 μ, striæ, 7—9 per 10 μ, $\frac{a}{t} = 3{\cdot}7—5{\cdot}1$.

f. *robusta;* a = 67—130 μ, t = 20—21 μ, striæ, 6 per 10 μ, $\frac{a}{-} = 4{\cdot}4—6{\cdot}3$.

Pl. I, fig. 4.

Var. *incudiformis*, Grun. in Cl. [83], p. 467, Pl. 36, figs. 26, 30.
Cl. Syn. II, p. 28. *Navicula incudiformis*, Grun. l. c.
Pl. I, fig. 5.

Like the principal species, but the valves have a distinct lateral area upon the side of the median rib that is turned away from the raphe.

Dimensions. a = 56—101 μ, t = 17—20 μ, striæ, 7 or 8 per 10 μ, $\frac{a}{t} = 3{\cdot}3—5{\cdot}5$.

27. *Navicula directa*, W. Sm. [53], p. 56, Pl. XVIII, fig. 172. Cl. Syn. II, p. 27.
Pl. I, figs. 1—3.

Valves narrow lanceolate, narrower than in the preceding species, almost symmetrical, with the central pores close together. The striæ at right angles to the median rib, and thus parallel with the transapical axis. Like Cleve, I can distinguish 3 varieties:

Var. *genuina*, Cl. Syn. II, p. 27. Pl. I, figs. 2, 3.

Dimensions. a = 54—112 μ, t = 9—11 μ, striæ, 8 or 9 per 10 μ, $\frac{a}{t} = 5—11$.

Var. *subtilis* (Greg.) Cl. *Pinnularia subtilis*, Greg. [57], p. 488, Pl. IX, fig. 19.

Dimensions. a = 84—93 μ, t = 7 μ, striæ, 9 per 10 μ, $\frac{a}{t} = 11—13$.

Var. *remota*, Grun. [80], p. 39. Pl. I, fig. 1.

Dimensions. a = 112—145 μ, t = 12—14 μ, striæ, 6 or 7 pr. 10 μ, $\frac{a}{t} = 9—12$.

All three varieties fairly frequent, var. *genuina* common.

Distribution. Northern shores, var. *remota* also in warmer seas.

28. *Navicula gelida*, Grun. [84], p. 103, Pl. A, figs. 27, 28. Cl. Syn. II, p. 28.
Pl. I, figs. 8, 9.

Under this species I have classed all the small forms that are nearly allied to *N. transitans* and *N. directa*, and have entire, slightly radiating striæ, and a narrow, but visible axial area.

Dimensions. a = 32—67 μ, t = 9.5—14 μ, striæ, 10—13 per 10 μ, $\frac{a}{t}$ = 2·4—5.

Common in most of the samples.

Distribution. Arctic waters.

29. *Navicula derasa,* Grun. [80], p. 39, Pl. II, fig. 46.
N. transitans v. *derasa,* Cl. Syn. II, p. 28.
Pl. I, fig. 6.

Like *N. transitans,* but symmetrical, without axial area, but with a distinct lateral area on each side of the rib. The central pores close together.

Dimensions. a = 56—96 μ, t = 16—21 μ, striæ, 6—9 per 10 μ, $\frac{a}{t}$ = 3·5—5·5.

Rather common.

Distribution. Polar Sea — Kara, Cape Deschneff, Wankarema, East Greenland.

Var. *erosa* (Cl.) [83], p. 468, Pl. 36, fig. 28. *Navicula erosa,* Cl. l. c.
N. transitans v. *erosa,* Cl. Syn. II, p. 28.

Is distinguished from the principal species by its greater breadth, and by the striation, which is interrupted by 2 or 3 areas on each side of the median rib.

Uncommon.

Distribution. The same as the principal species.

30. *Navicula detersa,* (Grun.) in Cl. [83], p. 469, Pl. 36, fig. 36.
Pl. I, fig. 7.

Navicula kariana v. *detersa,* Grun. l. c. Cl. Syn. II, p. 28.

Resembles the principal species of *N. derasa* in its striation and symmetrical proportions, but is broader in comparison to its length, the walls are thinner, and the striation is finer and fainter.

As the true *N. kariana* does not occur in the samples, I have preferred to enter this form under a special specific name.

Dimensions. a = 60—114 μ, t = 22—27 μ, $\frac{a}{t}$ = 2·7—4·2, striæ, 9—11 per 10 μ.

Common in most of the samples.

Distribution. Arctic waters.

31. *Navicula Blessingii*, n. sp.

Pl. I, fig. 10.

Valves flat, with parallel margins which curve together towards the obtusely triangular ends. Median rib and raphe as in *Navicula derasa;* axial area absent, but on both sides of the median rib there is a large lateral area. The fragments of striæ by the median rib are always visible on both sides of the rib near the middle of the valve; but near the extremities they often disappear on one side. Here, then, the lateral area goes right up to the raphe. It may probably be concluded from this that near the centre, the raphe keeps almost in the middle of the median rib, but near the extremities runs closer to the inner side of the rib.

This species resembles *Navicula trigonocephala* in the outline of the valves; but its valves are slightly curved, and the symmetry and striation are different. I have not succeeded in discovering transition-forms. It is probably identical with the form that Östrup has named *N. trigonocephala* v. *depressa*, Oestr. [95], p. 430, Pl. IV, fig. 44. The name *depressa*, however, cannot be used as the specific name, as it is already employed for another *Navicula*.

Dimensions. a = 41—69 μ, t = 13 or 14 μ, striæ, 8 or 9 per 10 μ, $\frac{a}{t}$ = 3—5.

Not uncommon in several of the samples.

B. *Rhoiconeis*, Grun. Valves unequal, more or less curved in the same direction, so that the one is convex, and the other concave, as in *Achnanthes*.

32. *Navicula trigonocephala*, Cl. [83], p. 468, Pl. 36, fig. 29. Östrup [95], p. 429, Pl. IV, figs. 45, 46. Cl. Syn. II, p. 27.

Pl. I, figs. 13, 14.

The valves are very slightly curved, somewhat unequal, as the striæ on the convex[1] valve are generally more entire than on the concave side. The median rib is somewhat unsymmetrical, the axial area distinct.

Dimensions. a = 32—72 μ, t = 12—14 μ, $\frac{a}{t}$ = 2·3—5·3, striæ 8—10 per 10 μ.

Fairly common in most of the samples.

Distribution. Arctic waters — Wankarema, East Greenland.

33. *Navicula recurvata,* n. sp.

Pl. II, figs. 12—15.

Valves bluntly lanceolate in outline, evenly arcuate, but not vaulted. The median rib symmetrical as in *N. derasa* and *N. detersa.* The valves are unequal, the convex valve having entire striæ, while the concave has a large lateral area on each side of the median rib.

The pleuræ in this species form such narrow bands, that the distance of the valves from one another is not great.

The concave valve of this species strongly resembles diminutive forms of *Navicula derasa;* but its curvature distinguishes it decidedly from that species. It also resembles *Navicula finmarchica,* Cl. & Grun., *Stauroneis finmarchica,* Cl. & Grun. [80], p. 47, Pl. III, fig. 63; but Cleve states that the valves in that species are uniform (Syn. II, p. 28).

Dimensions. a = 27—62 μ, t = 8—12 μ, striæ, 9 or 10 per 10 μ, $\frac{a}{t}$ = 3—5.

Fairly common.

34. *Navicula superba,* s. l.

Valves unequal, considerably vaulted, with coarse, strongly marked striation. The keel on the convex valve is fairly evenly curved; on the concave valve it is straighter, but with a break inwards in the middle. Both valves are asymmetrical in build, with a distinct, unilateral axial area. On the opposite side, the concave valve has a lateral area, which is poorly

[1] Considered from the outside.

developed in the narrower forms, well developed in the broader forms. The central pores of the raphe are at a considerable distance from one another. The pleuræ of the cells form a comparatively broad band, and the length of the pervalvar axis is still further increased by the high vaulting of the valve.

The contour of the valves varies exceedingly, in the same manner as in the series of forms that are grouped about *Pinnularia quadratarea* (A. Schm.) Cl. The following principal types may be distinguished:

Sub-sp. 1. *Navicula sibirica* (Grun.) Cl.

Pl. II, figs. 7—11.

N. Bolleana var. ? *sibirica*, Grun. in Cl. [83] p. 469, Pl. 37, fig. 38.

N. sibirica, Cl. Syn. II, p. 29.

Syn. *N. Bolleana* var. *asymmetrica*, Cl. [83], p. 469, Pl. 37, fig. 39.

N. Bolleana v. *intermedia*, Oestr. [95], p. 431, Pl. V, fig. 51.

N. sibirica v. *asymmetrica*, Cl. Syn. II, p. 29.

Contour of the valves of a narrow rhombic or lanceolate form, sometimes with pointed extremities. Var. *asymmetrica* corresponds with the concave valve, while the convex one looks like the typical *N. sibirica*, (Grun.).

Dimensions. a = 33—67 μ, t = 8—12 μ, $\frac{a}{t}$ = 3—6.6, striæ, 8 or 9 per 10 μ.

Common in most of the samples.

Distribution. Arctic waters, on ice — Wankarema, East Greenland.

Sub-sp. 2. *Navicula superba*, Cl. s. s.

Pl. II, figs. 1—3.

Cl. [83], p. 468, Pl. 36, fig. 23. Cl. Syn. II, p. 29.

Contour of the valves broadly rhombic or elliptical (var. *elliptica*, Cl.).

Dimensions. a = 34—95 μ, t = 18—22 μ, $\frac{a}{t}$ = 1·9—4·4, striæ, 7—9 per 10 μ.

Var. *subacuta*, n. var.

Pl. II, fig. 4.

Valves somewhat pointed, otherwise like the principal species.

Var. *elliptica,* Cl. [83], p. 469, Pl. 36, fig. 23.

Valves elliptical in contour, otherwise like the principal species.

Var. *crassa* (Oestr.). *N. erosa* v. *crassa,* Oestr. [95], p. 429, Pl. VIII, fig. 94.

Pl. II, fig. 5.

Contour as in var. *elliptica;* striæ somewhat closer together than in the principal species, divided into several portions, with narrow, longitudinal lateral areas.

Dimensions. a = 50—90 μ, t = 21—27 μ, $\frac{a}{t}$ = 2·1—3·3, striæ, 8 or 9 per 10 μ.

Fairly common, especially the principal species.

Distribution. Arctic waters, on ice — Wankarema, East Greenland.

Sub-sp. 3. *Navicula obtusa,* Cl. [83], p. 469, Pl. 36, fig. 25. Cl. Syn. II, p. 29.

Pl. II, fig. 6.

Contour of the valves linear, sometimes constricted in the middle (f. *amphiglottis,* Oestr.), with bluntly rounded ends.

Dimensions. a = 50—106 μ, t = 15 μ, striæ, 9 or 10 per 10 μ, $\frac{a}{t}$ = 3·5—7·3.

Not uncommon.

Distribution. Arctic waters, on ice — Wankarema, E. Greenland.

NAVICULÆ PUNCTATÆ, Cl.

35. *Navicula algida,* Grun. [84], p. 56, Pl. A, fig. 31. Cl. Syn. II, p. 40.

Dimensions. a = 45—91 μ, t = 21—55 μ.

Not uncommon.

Distribution. North Siberia; E. Greenland, on ice.

36. *Navicula glacialis,* (Cl.) Grun.

Cocconeis glacialis, Cl. [73], p. 14, Pl. III, fig. 12.

Navicula glacialis, Grun. [84], p. 55. Cl. Syn. II, p. 40.

Not uncommon.

Distribution. Arctic and Antarctic Oceans.

NAVICULÆ LYRATÆ, Cl.

37. *Navicula forcipata,* Grev. [59], p. 83, Pl. VI, figs. 10, 11. Cl. Syn. II, p. 65.

Dimensions. a = 39—46 μ, t = 15 or 16 μ, striæ, 17—19 per 10 μ.

Rather uncommon.

Distribution. In brackish water, especially on northern coasts.

PINNULARIA, Ehb.

38. *Pinnularia borealis,* Ehb. [43], Pl. I, 2, fig. 6. Cl. Syn. II, p. 80.

Occurs singly.

Distribution. In fresh water, especially in cold climates and on mountains.

39. *Pinnularia perlucens,* Oestr. [95], p. 421, Pl. III, fig. 14.

Navicula perlucens, Oestr. l. c.

On ice in the Barents Sea; not in the other samples.

Distribution. On ice off E. Greenland.

40. *Pinnularia ambigua,* Cl. Syn. II, p. 94.

Pl. III, figs. 1 & 2.

Navicula retusa, Grun. [80], p. 38. Cl. [83], p. 470, Pl. 36, fig. 35.

Östrup [95], p. 432.

Valves highly vaulted, keel bent in in the middle, out at the extremities.

Dimensions. a = 23—87 μ, t = 7 or 8 μ, striæ, 9 or 10 per 10 μ.

Distribution. Northern coasts; on ice at Wankarema, East Greenland, Cape Eglinton.

41. *Pinnularia quadratarea,* (A. Schm.) Cleve. Syn. II, p. 95.

Navicula quadratarea, A. Schm. [74], Pl. II, fig. 26.

Navicula Pinnularia, Cl. [68], p. 224, Pl. IV, figs. 1, 2.

Pl. III, figs. 3—6.

Occurs, as in the collection from Wankarema and from the ice-floes off East Greenland, in a large number of forms, which would each have been considered a good species, if every possible transition-form had not existed.

The typical form with linear valves is rather rare; the others can be most conveniently arranged under the following principal types:

Var. *β. Stuxbergii,* Cl. [80], p. 13, Pl. I, fig. 15. Cl. Syn. II, p. 96. Pl. III, fig. 3.

Contour of the valves elliptical lanceolate, broadest in the middle.

Dimensions. a = 43—104 *μ*, t = 15—20 *μ*, striæ, 8—10 per 10 *μ*.

Certain dwarf forms (e. g. f. *minima,* Oestr.) may be even smaller. In the collection under discussion, there are forms that are altogether identical with the above-mentioned form.

Dimensions. a = 22 *μ*, t = 8 *μ*, striæ, 10 per 10 *μ*.

Under this type are classed the following forms:

f. *leptostauron,* Grun. [84], p. 103, Pl. A, fig. 32.

f. *subcontinua,* Grun. [84], p. 103, Pl. A, fig. 33.

f. *Theelii,* Cl. [80], Pl. I, fig. 22. *Navicula Theelii,* Cl. l. c. p. 13.

f. *subglabra,* Oestr. [95], p. 421, Pl. IV, fig. 27. *Navicula Stuxbergii* var. *subglabra,* Oestr. l. c.

f. *cuneata,* Oestr. [95] p. 421, Pl. IV, fig. 37. *Navicula Stuxbergii* var. *cuneata,* Oestr. l. c.

f. *minima,* Oestr. [95], p. 420, Pl. IV, fig. 29. *Navicula Pinnularia* var. *minima,* Oestr. l. c.

Common under various forms in most of the samples.

Distribution. Arctic waters, on ice.

Var. *γ. bicontracta,* Oestr. [95], p. 419, Pl. IV, fig. 34. Pl. III, fig. 5.

The valves widen in the middle, thence tapering, and often again slightly wider near the extremities.

Dimensions. a = 46—113 *μ*, t = 10—17 *μ*, striæ, 8—11 per 10 *μ*.

f. *gibbosa,* Oestr. (a = 27 *μ*, t = 9 *μ*) is a dwarf form belonging to this variety.

The following forms also come under the above variety:

f. *maxima,* Oestr. [95], p. 418, Pl. IV, fig. 22. *N. Pinnularia* v. *maxima,* Oestr. l. c.

f. *gibbosa,* Oestr. [95], p. 420, Pl. IV, fig. 28. *N. Pinnularia* v. *gibbosa,* Oestr. l. c.

f. *densestriata,* Cl. [96, 1], p. 22, Pl. I, fig. 8. *P. quadratarea* v. *densestriata,* Cl. l. c.

Not uncommon, both large and small forms.

Var. *δ. constricta,* Oestr. [95], p. 419, Pl. IV, figs. 23, 24.
Pl. III, fig. 4.

The valves more or less constricted in the middle, with the ends tapering to a blunt triangle.

Dimensions. a = 42—80 μ, t = 13—17 μ (greatest width), striæ, 9 or 10 per 10 μ.

The following form comes under this variety:

f. *subconstricta,* Oestr. [95], p. 419, Pl. IV, fig. 25.

Fairly frequent.

Distribution. East Greenland, upon ice.

42. *Pinnularia semiinflata,* (Oestr.) [95], p. 422, Pl. IV, fig. 39.

Navicula semiinflata, Oestr. l. c.

As Cleve remarks ([96, 1], p. 19), this species is very nearly allied to *P. quadratarea.* It is especially distinguished from that species by the circumstance that the raphe does not reach quite to the ends of the valve, so that a radiating striation is visible round the apical areas. In most of its forms, moreover, this species exhibits a peculiar tendency towards unsymmetrical development.

The following principal types may be distinguished:

Var. *α. genuina. Navicula semiinflata,* Oestr. l. c.
Pl. III, fig. 7.

Striæ unbroken, valves linear in outline, with rounded extremities and a protuberance on one side, where the central area goes quite up to the margin.

Dimensions. a = 21—60 μ, t = 10 or 11 μ, striæ, 12—14 per 10 μ.

Fairly common.

Distribution. East Greenland, on ice.

Var. *β. decipiens,* (Cl.). *Navicula decipiens,* Cl. [96, 1], p. 19, Pl. I, fig. 3 (not fig. 4).

Navicula latefasciata var. *angusta,* Oestr. [95], p. 422, Pl. IV, fig. 35.

Navicula glacialis var. Cl. [83], Pl. 37, fig. 41.

Pl. III, fig. 8.

The striæ on both sides of the raphe are divided into two by a linear lateral area, which does not, however, reach to the end of the valves. The valves are almost symmetrical; the central area is somewhat unilaterally expanded, but does not always reach the margin of the valves.

Dimensions. a = 41—62 μ, t = 11 or 12 μ, striæ, 13 or 14 per 10 μ.

Scarce.

Distribution. North Siberia (Wankarema) and E. Greenland, on ice.

Var. *γ. inæqualis,* Oestr. [95], p. 433, Pl. V, fig. 53.

Navicula glacialis var. *inæqualis,* Oestr. l. c.

Navicula decipiens var. Cl. [96, 1], p. 19, Pl. I, fig. 4.

The striæ divided into several portions. The valves more or less asymmetrical, but not protruding in the middle; the central area goes right to the margin on one side.

Dimensions. a = 36—42 μ, t = 15—17 μ, striæ, 14—17 per 10 μ.

Scarce.

Distribution. East Greenland, on ice.

AMPHORA, Ehb.

43. *Amphora lævis,* Greg. [57], p. 514, Pl. XII, fig. 74 a, b, c.

Var. *lævissima,* (Greg.), Cl. Syn. II, p. 130.

A. lævissima, Greg. [57], p. 513, Pl. XII, fig. 72.

Not uncommon.

Distribution. Northern coasts, North Siberia and East Greenland, upon ice.

B. PSEUDORAPHIDEÆ.

FRAGILARIA, Lyngbye.

44. *Fragilaria oceanica,* Cl. [73], p. 22, Pl. IV, fig. 25. Grun. [84], p. 107, Pl. B, fig. 14 a, b.

F. arctica, Grun. [80], p. 110, Pl. 7, fig. 124. De Toni Sylloge [92], p. 685.

Common in most of the samples, sometimes the predominating species.

Distribution. Northern coasts, in the neritic plankton, and on ice.

45. *Fragilaria cylindrus,* Grun. [84], p. 107, Pl. B, fig. 13. De Toni [92], p. 684. Gran [97, 2], p. 8, Pl. I, figs. 4, 5.

Common in most of the samples.

Distribution. Like the preceding species, but only on the shores of the Arctic Ocean.

46. *Fragilaria Harrisonii,* (W. Sm.) Grun.

Odontidium Harrisonii, W. Sm. [56], p. 18, Pl. 60, fig. 373. De Toni [92], p. 639.

Occurs singly.

Distribution. Fresh water, Northern Europe.

SURIRELLA, Turpin.

47. *Surirella Oestrupii,* nov. nom.

Surirella splendida var.? *minima,* Oestr. [95], p. 449, Pl. VI, fig. 68.

This species, which is characteristic of the flora on the ice, ought to have a specific name of its own, at any rate as long as its systematic position is so little known. It differs not a little from the typical *Surirella splendida.* As the variety name, *minima,* is not very appropriate as a specific name, I have preferred to name it after its discoverer.

Dimensions. $a = 20—36\ \mu$, $t = 11—17\ \mu$, $\frac{a}{t} = 1{\cdot}75—2{\cdot}2$.

Not uncommon.

Distribution. East Greenland, on ice-floes.

HANTSCHIA, Grun.

48. *Hantschia Weyprechtii*, Grun. [80], p. 104, [84], p. 107, Pl. A, fig. 60.
Not uncommon.
Distribution. North Siberia (Grunow), E. Greenland (Östrup), both places on ice.

NITZSCHIA, (Hassall) Grun.

49. *Nitzschia denticula*, Grun. 80, p. 82.
Occurs singly.
Distribution. In fresh water in Europe, Siberia, etc.

50. *Nitzschia hybrida*, Grun. [80], p. 79, Pl. V, fig. 95.
Grun. [84], p. 107, Pl. A, fig. 61. De Toni [92], p. 513.
Fairly common.
Distribution. The shores of the N. Atlantic and Arctic Oceans.

51. *Nitzschia distans*, Greg. [57], p. 530, Pl. VI, fig. 103. De Toni [92], p. 524.
Fairly common.
Distribution. Scattered along various coasts.

52. *Nitzschia Brebissonii*, W. Sm.
Var. *borealis*, Grun. in Cl. & Möll. Diat., Nos. 315—318 seq.
Cl. [96, 1], p. 21).
N. socialis var. *septentrionalis*, Oestr. [95], p. 445, Pl. VII, fig. 80.
Not uncommon.
Distribution. Wankarema, East Greenland, upon ice.

53. *Nitzschia lævissima*, Grun. [84], p. 106, Pl. A, figs. 65, 66. De Toni [92], p. 533.
Common.
Distribution. North Siberia, Wankarema, E. Greenland, always on ice.

54. *Nitzschia gelida,* Cl. & Grun. in Cl. [83], p. 480, Pl. 38, fig. 70.

Fairly common.

Distribution. Wankarema, E. Greenland, at both places on ice.

55. *Nitzschia polaris,* Grun. in Cl. & Möll. Diat., No. 314. Grun. [84], p. 106, Pl. A, figs. 62, 63.

Common.

Distribution. Wankarema, near Franz Josef Land, E. Greenland, always on ice.

56. *Nitzschia frigida,* Grun. [80], p. 94, Pl. V, fig. 101. De Toni [92], p. 537. Gran. [97, 2], p. 22, Pl. I, fig. 11.

Very common, predominating in several of the samples. Occurs generally in whole colonies, as figured by Gran, l. c.

Distribution. Shores of the Arctic Ocean, on ice and as plankton; widely distributed.

57. *Nitzschia lanceolata,* W. Sm.

Var. *pygmæa,* Cl. [84], p. 481. [96, 1], p. 22, Pl. I, figs. 19, 20.

Not uncommon.

Distribution. Wankarema, on ice; Cape Eglinton, floating freely.

58. *Nitzschia acicularis,* Kütz.

To this species I have referred some acicular cells that occur in great quantities in several of the samples. Cleve found it in the plankton in the Barents Sea, together with *Melosira hyperborea, Nitzschia frigida,* and others (Cl. [98], p. 26).

59. *Nitzschia Closterium,* (Ehr.) W. Sm. De Toni [92], p. 548.

Rather scarce.

Distribution. Shores of the Atlantic and Arctic Oceans. Lives especially in masses of mucilage.

C. CENTRICÆ.

CHÆTOCERAS, Ehr.

Sub-genus I. *Phœoceras,* Gran.

60. *Chœtoceras criophilum,* Castr. [86], p. 78.

As plankton rare, as fragments on the ice scarce.

Distribution. Oceanic plankton organisms, especially in northern seas.

61. *Chœtoceras boreale,* Bail.

In immense quantities in a few plankton samples, frequently in the shape of fragments on the ice. The form occurring is the typical one which, for instance, is figured in Cleve [97], Pl. I, figs. 1, 2 (incl. f. *Brightwellii,* Cl.).

Distribution. In all seas in the oceanic plankton.

Sub-genus II. *Hyalochæte,* Gran.

62. *Chœtoceras decipiens,* Cl. [73], p. 11, Pl. I, fig. 5.

Not uncommon in plankton samples and as fragments on the ice.

Distribution. Oceanic, especially in northern seas.

63. *Chœtoceras Mitra,* (Bail.) Cl. [96, 1], p. 8, Pl. II, figs. 1, 2. *Dicladia Mitra,* Bail.

Spores *(Dicladia)* on the ice; rare.

Distribution. Shores of the Arctic Ocean, neritic.

64. *Chœtoceras teres,* Cl. [96, 2], p. 30, Pl. I, fig. 7.

f. *spinulosa,* n. f.

Pl. III, fig. 10.

Spores on the ice; not uncommon. The secondary valve of the spores is more strongly armed than in the form that occurs on the coasts of Northern Europe. The secondary valve in the European form is smooth or furnished with fine hairs (*Ch. commutatus,* ? Cl. [96, 2], Pl. I, fig. 11).

Distribution. Principal form neritic on the coasts of Northern Europe.

65. *Chætoceras contortum,* Schütt [95], p. 44. Gran [97, 1], p. 14, Pl. II, fig. 32.

In plankton samples with spores. Isolated spores on the ice not uncommon.

Distribution. Coasts of Northern Europe and Greenland, neritic.

66. *Chætoceras diadema,* (Ehr.) Gran [97, 1], p. 20, Pl. 2, figs. 16—18.

Spores on the ice fairly common.

Distribution. Neritic on the coasts of Europe and Greenland, probably almost cosmopolitan.

67. *Chætoceras debile,* Cl. [94], p. 13, Pl. I, fig. 2. Gran [97, 1], p. 23, Pl. 2, figs. 14, 15.

Spores in and on the ice not uncommon.

Distribution. Neritic on the coasts of Northern Europe and Greenland.

68. *Chætoceras sociale,* Lauder [64], p. 77, Pl. 8, fig. 1.

A few smooth little spores belong in all probability to this species.

Distribution. Northern Europe, Greenland, Hongkong.

69. *Chætoceras Wighami,* Brightw. [56], p. 108, Pl. VII, figs. 19—36.

Syn. *Ch. bottnicum,* Cl. in Aurivillius [96], p. 14, Pl. 1.

Ch. biconcavum, Gran [97, 1], p. 27, Pl. 3, fig. 46.

Spores and whole chains frozen into the ice.

Distribution. Northern Europe, East Greenland.

70. *Chætoceras furcellatum,* Bail. [56], Pl. I, fig. 4. Gran [97, 2], p. 19, Pl. I, figs. 15, 16.

Spores on the ice, rather rare.

Distribution. Shores of the Arctic Ocean and most northerly parts of Europe, neritic.

71. *Chætoceras septentrionale,* Oestr. [95], p. 457, Pl. VII, fig. 88. Cl. [96, 1], p. 9, Pl. II, fig. 8.

Fairly common on the ice, sometimes with spores. Perhaps identical with *Ch. gracile,* Schütt, occurring on the coasts of Northern Europe.

Distribution. East Greenland, Baffin's Bay, on ice and in plankton.

XANTHIOPYXIS, Ehr.

Only fossil specimens of this peculiar genus have been found hitherto. In the samples from the polar ice, one species was found, sometimes in considerable quantities; but nevertheless, it is unfortunately impossible to clear up the systematic position of the genus. The cell-wall is silicified, and it easily divides into two when treated with acid, one part larger than the other. It is therefore probable that the genus belongs to the Bacillariaceæ; but it differs from all other Bacillariaceæ in having no connecting zone (pleura) between the valves. Cell-division, notwithstanding my diligent searching, I have been unable to find; nor is it easy to imagine how it takes place, if it is to be like the the cell-division of the other diatoms.

It is more probable that *Xanthiopyxis* represents a quiescent stage of some diatom. In such a case too, it would differ from all other known spores, as these always have a smooth, cylindrical portion, leaning directly against the wall of the mother-cell. *Xanthiopyxis* has long spines projecting in all directions; and if it is a spore that is formed inside another cell, it must necessarily be freely suspended in that cell. I once thought I saw a half decomposed cell-wall which resembled that of a *Chætoceras,* outside a *Xanthiopyxis* cell; but is was impossible to determine it with certainty.

The form found on the ice-floes is not unlike several of the fossil species described by Ehrenberg. I cannot, however, with certainty indentify it with any of these, but consider it advisable in the mean time to give it a name of its own.

72. *Xanthiopyxis polaris,* n. sp.

Pl. III, figs. 16—19.

The cells irregularly elliptoid with an almost cylindrical median part; armed all over with pointed, narrowly conical spines, projecting at right

angles to the surface. The cell-wall consists of two valves, one of which forms a flat spherical calotte, the other being larger and almost cylindrical, with a hemispherical bottom.

THALASSIOSIRA, Cl.

73. *Thalassiosira Nordenskiœldii,* Cl. [73], p. 7, Pl. I, fig. 1.

Fairly frequent in some of the samples.

Distribution. Neritic on the coasts of Northern Europe and Greenland.

74. *Thalassiosira gravida,* Cl. [96, 1], p. 12, Pl. II, figs. 14—16.

Spores (*Coscinodiscus subglobosus,* Grun.) sometimes free, sometimes in their mother-cells on the ice and frozen into it. Diam. = 20—36 μ.

Distribution. Neritic on the coasts of Greenland and Northern Europe.

MELOSIRA, Agardh.

75. *Melosira hyperborea,* (Grun.) in V. Heurck Syn. Pl. 85, figs. 3, 4.

Melosira nummuloides var.? *hyperborea,* Grun. l. c.

Gallionella nummuloides var. *hyperborea,* De Toni [94], p. 1331.

Pl. III, figs. 11—15.

This species seems to be very characteristic of the ice-floes in the Polar Sea. It may also develope in great quantities as plankton among the ice. It represents one of the most simply constructed types of the genus *Melosira.* The valves are hemispherical with an annular rim outside near the top, to which the cells hang in chains. The edges of the valves are strengthened internally by a narrow fillet. The pleura consists of a tolerably broad band, which forms a cylinder; the younger of the valves, however, only forms its band immediately before a cell-division. Until this takes place, it leans with its margin against the fillet of the outer valve, while the band of the outer valve envelopes it like a mantle. The form of the cell is thus spherical or elliptoid, being surrounded on one side, from the greatest circumference to the pole, with a hollow, empty cylinder. When the cell-division is to take

place, the pleura of the inner valve gradually grows, and thus forces the valve out, the edge always being supported by the fillet of the outer valve.

In the cell-division, the new valves are formed centrifugally. First the central part of the valves is formed, by which they immediately become connected; but the young valves, from the first, lie unattached in the central protoplasm.

The spores are formed under very peculiar circumstances. As a rule, the spore-formation begins like an ordinary cell-division, except that the newly-formed valves are thicker than the ordinary vegetative ones. They are furnished with a network of ribs outside, wherever the wall is not in close contact with other cell-walls, either the valve of the sister-cell, or the pleura of the mother-cell. This first-formed valve (primary valve) thus consists of 3 parts, viz. (1) a circular disc which is hollowed out a little inside, flat outside, and covered with fine puncta, (2) a spherical zone which is strengthened outside with strong ribs, and (3) a cylindrical mantle, which is smooth, and lies close to the pleura of the mother-cell.

After this process, the protoplasm generally draws away from the older, thin valve of the mother-cell, and collects about the newly-formed spore valve. A hemispherical secondary valve is then formed, which resembles the primary valve, but is without the flat, smooth part on the top; and thus the spore is complete. In this way the spores come to lie in pairs, in the same manner, for instance, as in *Chætoceras furcellatum*.

Figs. 12, 13, Pl. III, represent chains with spore formation, which in one respect, differs from the normal formation. After the primary valves of the spores are formed, the new cells have taken the first steps towards yet another cell-division. This has advanced so far, that two new rudiments of valves have appeared; but only one of these has grown fully. It has become the secondary valve of the spore; the other is lying unattached in the cell, and the protoplasm has wandered almost completely into the spore.

The occurrence of such divisions shows that the spore-formation is in reality a special, reduced form of ordinary cell-division, just as Karsten [99] has found to be the case with the auxospore-formation.

Yet another form of spore-formation may occur in *Melosira hyperborea*. A single spore may be formed right inside a cell, in the same manner, for instance, as in *Chætoceras diadema* and *Thalassiosira gravida*. This

however, only occurs in rare instances. While the spore-formation of the more highly organised species is determined, so that it occurs either in one way or the other, *Melosira* has kept both the principal forms. I have also found similar conditions in *Thalassiosira Nordenskiœldii*.

The auxospore-formation is figured by Vanhöffen [97], Pl. III, fig. 18.

Common in all the samples, sometimes in great quantities, predominating.

Distribution. The Polar Sea and its shores, on ice and as plankton.

76. *Melosira crenulata* (Ehr.) Kütz. [44], p. 55, Pl. 2, fig. VIII.

Occurs singly, rather more frequently in the sample from Franz Josef Land.

Distribution. In fresh water, Northern Europe, N. America.

ACTINOCYCLUS, Ehr.

77. *Actinocyclus alienus*, Grun.

Var. *arctica*, Grun. in V. H.'s Syn. Pl. 125, fig. 12. Cl. [96, 1], Pl. II, figs. 11, 12.

Diameter = 57—74 μ.

This form, whose systematic position on the whole is doubtful, is found rather plentifully in several of the samples. In pools on the ice and in water melted from ice, it is not infrequently found with spores, a new valve being formed within each of the old ones, and somewhat thicker than they; but they are of the same structure.

The species has been, to some extent at any rate, confused with *Podosira glacialis*, Grun. So little has as yet been done towards the systematisation of these forms, that in a revision it is probable that altogether different characters would be employed for the division of the genera from those now in use; the genera *Coscinodiscus, Podosira, Lauderia, Thalassiosira*, and to some extent *Actinocyclus*, would have to be defined in a very different manner to that which is at present in use.

Distribution. Arctic Ocean, on ice (and in plankton?).

COSCINODISCUS, Ehr.

78. *Coscinodiscus oculus iridis,* Ehr. [39], p. 147. De Toni [94], p. 1275.
Not uncommon on the ice, solitary occurrences in plankton.
Distribution. In the plankton of all oceans.

79. *Coscinodiscus polyacanthus,* Grun. [80], p. 112, Pl. VII, fig. 127.
De Toni [94], p. 1234.
In large quantities on ice-floes off Franz Josef Land, otherwise rare. Diameter = 16—42 μ. Rows of puncta, 14—16 per 10 μ.
Distribution. The northern Polar Sea.

80. *Coscinodiscus curvatulus,* Grun. in A. Schmidt Atlas, Pl. 57, fig. 33.
Grun. [84], p. 83, Pl. D, figs. 11—14. De Toni [94], p. 1226.
Scarce. Diameter = 37—72 μ.
Distribution. Shores of various oceans.

81. *Coscinodiscus Kützingii,* A. Schm. Atl. Pl. 57, figs. 17, 18.
Var. *glacialis,* Grun. [84], p. 84, Pl. D, fig. 18. De Toni [94], p. 1222.
Not uncommon. Diameter = 38—73 μ.
Distribution. Arctic Ocean (Wankarema, Franz Josef Land, Greenland), especially on ice.

82. *Coscinodiscus bioculatus,* Grun. [84], p. 107, Pl. C, fig. 30. De Toni [94], p. 1225.
Not uncommon. As Cleve remarks [96, 1], the cells form rather high cylinders, as there are several annular intermediate ribbons (copulæ) between the valves and the pleuræ. In this respect, the species resembles the genus *Lauderia.*
Distribution. Arctic Ocean, especially on ice-floes.

83. *Coscinodiscus septentrionalis*, Grun. [84], p. 85, Pl. D, figs. 28—33.

C. lacustris var.? *septentrionalis*, Grun. l. c. De Toni [94], p. 1290.

Fairly common.

Distribution. Shores of the Arctic and Atlantic Oceans.

TABLE I. CONTENTS OF THE PLANKTON SAMPLES.

Year.	1893		1894			1896	
Date	12th Oct.	13th Oct.	24th Oct.	22nd May	22nd June	20th Oct.	4th Feb.
Latitude, N.	78° 13′	78° 14′	78° 20′	81° 24′	81° 45′	82°	84° 40′
Longitude, E.	135° 55′	136°	c. 136°	125° 20′	121° 20′	115°	24° 38′
Depth	0—50 m.	0—50 m.	0—20 m.	0—100 m.		0—50 m.	0—100 m.
Chætoceras boreale, Bail. .	*cc*	*cc*	*cc*				*r*
— *contortum*, Schütt.	*r*						
— *criophilum*, Castr.		*r*					
— *decipiens*, Cl.	+	+	+				
Coscinodiscus oculus iridis, Ehr.		*r*		*r*		*r*	
Fragilaria oceanica, Cl. .					*r*		

cc = abundant, + = rather common, *r* = scarce.

In the following samples, no traces of diatoms could be found:

Year.	Month.	Date.	N. Latitude.	E. Longitude.	Depth.
1894	February	21	80° 4′	134°	0—100 m.
—	March	17	79° 37′	135° 15′	0—100 m.
—	—	20	79° 40′	135° 15′	0—8 m.
—	—	24	80° 1′	135° 40′	0—c. 270 m.
—	April	11	80° 17′	134°	0—300 m.
—	—	13	80° 17′	134°	0—40 m.
—	—	19	80° 27′	132°	0—40 m.
—	—	21	80° 28′	131° 8′	0—250 m.
—	—	25	80° 30′	131° 30′	0—250 m.
—	May	1	80° 44′	131° 30′	0—75 m.

TABLE II. CONTENTS OF THE MOST

	Water melted from new ice.		Ponds on the ice, not communicating with the sea.			Diatoms on					
Date.	Oct. 18, 1893.	Oct. 20, 1893.	July 22, 1894.	July 24, 1894.			July 20, 1894.		July 24, 1894.		
Locality.	N. 78° 19′ E. 136° 16′		N. 81° 28′ E. 125° 1′	N. 81° 24′ E. 125° 1′			N. 81° 30′ E. 125° 10′		N. 81° 24′ E. 125° 1′		
No. of the sample.	8	6	7	2	5	17	4	11	14	15	16	18
1. *Amphiprora paludosa* v. *punctulata*	..	..	..	..	..	..	..	..	..	..	..	..
2. — *Kjellmanii*	..	..	..	+	..	..	..	..	..	..	..	..
— — v. *glacialis* .	..	..	..	..	..	..	..	..	..	..	..	..
— — v. *striolata* .	..	..	..	..	..	..	..	..	..	..	..	..
— — v. *kryophila*	..	..	..	+	+	+	..	+	..	..	..	..
3. — *gigantea* v. *septentrionalis*	..	..	..	..	+	..	..	..	..	..	..	..
4. *Tropidoneis maxima* v. *dubia*	..	..	..	..	..	..	..	..	..	..	..	..
5. *Pleurosigma Clevei* v. *sibirica*	..	..	..	..	..	..	..	..	..	..	..	..
6. — *Stuxbergii*	+	+	+	..	..	..	..	..	..	..	..	+
— — v. *rhomboides*	..	..	..	..	..	..	+	..	..	..	..	+
7. *Caloneis kryophila*	..	..	+	+	..	..	..	..	..	..	..	+
8. *Diploneis didyma*	..	..	..	..	..	..	..	..	..	..	..	..
9. — *litoralis* v. *arctica*	..	..	..	+	+	..	..	+	..	..	..	+
10. — *Smithii*	..	..	..	..	..	..	+	..	..	..	..	..
11. *Navicula lineola*	..	..	..	..	..	..	..	..	..	..	..	..
12. — *Oestrupii*	..	..	..	+	..	..	..	..	..	..	..	..
13. — *kryokonites* . . .	..	..	..	+	+	..	..	..	..	..	+	..
14. — *Spicula*	..	..	..	..	..	..	..	+	..	..	..	+
15. — *vitrea*	..	..	..	..	..	..	..	..	..	..	..	+
16. — *Kjellmanii* . . .	..	..	..	..	..	..	..	..	..	..	..	..
17. *Stenoneis inconspicua* v. *Baculus*	..	..	..	..	..	..	+	..	..	..	+	+
18. *Navicula subinflata* . . .	..	..	+	+	+	+	..	+	..	..	..	+
19. — *pellucida*	..	..	..	..	..	..	..	..	..	..	..	..
20. — *septentrionalis* .	..	..	..	..	..	..	..	..	+	..	..	..

IMPORTANT SAMPLES FROM THE ICE.

the ice-foot.				Lumps in open channels.									Green ice and snow, Aug. 5, 1894.	Dirt on the ice.	Barents Sea, Aug. 8, 1896.
July 27, 1894.		Aug. 5, 1894.		July 18, 1894.	July 20, 1894.	July 24, 1894.			Aug. 3, 1894.	Aug. 5, 1894.					
N. 81° 15′ E. 125° 25′		N. 81° 7′ E. 127° 30′		N. 81° 26′ E. 125° 10′	N. 81° 30′ E. 125° 10′	N. 81° 24′ E. 125° 1′			N. 81° 5′ E. 127° 19′	N. 81° 7′ E. 127° 30′					
21	22	24	25	1	10	9	19	20	3	23	28	29	26	27	30
..	..	..	..	+	..	..	+	+	..	+	..	..	..	..	..
..	+	..	..	..	..	+	..	..	..	..	..	+	..	..	..
..	..	..	..	+	..	..	..	+	+	+	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
+	..	..	+	..	..	..	..	..	..	..	..	+	..	..	..
..	+	..	..	..	..	..	..	..	+	..	..	..	..	..	..
..	+	..	..	..	+	..	..	..	..	+	..	..	..	..	..
..	+	..	..	..	..	..	..	..	..	+	..	..	..	..	..
+	+	+	+	+	+	..	..	+	..	+	..	+	..	..	..
..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..
+	+	..	..	..	..	..	..	..	..	..	..	+	..	..	..
..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..
+	+	..	+	+	+	+	..	+	+	+	+	+	..	+	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	+	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	+	+	..	..	..	+	..	+	..	..	..	..	..
..	+	..	+	+	..	..	..	..	..	+	+	+	+	..	+
..	+	..	+	+	+	+	..	+	..	+	+	..	..	..	..
+	+	..	+	..	..	..	..	..	..	..	..	..	..	..	..
..	+	..	.	..	..	+	..	..	..	..	..	..	..	..	..
..	+	..	+	+	+	..	..	+	+	+	..	..	..	..	..
+	+	+	+	..	+	..	..	..	+	..	+	+	+	+	..
..	+	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	+	+	..	+	..	..	..	..	..	..	..	..	..	..	..

TABLE II (continued). **CONTENTS OF THE MOST**

	Water melted from new ice.		Ponds on the ice, not communicating with the sea.			Diatoms on					
Date.	Oct. 18, 1893.	Oct. 20, 1893.	July 22, 1894.	July 24, 1894.			July 20, 1894.		July 24, 1894.		
Locality.	N. 78° 19′ E. 136° 16′		N. 81° 28′ E. 125° 1′	N. 81° 24′ E. 125° 1′			N. 81° 30′ E. 125° 10′		N. 81° 24′ E. 125° 1′		
No. of the sample.	8	6	7	2	5	17	4	11	14	15	16	18
21. *Cymbella cuspidata* . . .	..	..	..	+	..	..	..	..	..	..	..	..
22. *Gomphonema exiguum* v. *pachyclada*	..	..	..	+	..	..	..	..	..	..	..	..
— *exiguum* v. *arctica*	..	..	..	+	+	..	+	+	+	+	+	+
23. — *kamtschaticum* v. *grœnlandica*	..	..	..	+	..	+	+	+	+	+	+	+
24. *Navicula rhynchocephala*	..	..	..	+	..	..	..	..	..	..	..	..
25. — *valida*	..	..	..	+	..	..	+	..	..	..	..	..
26. — *transitans* . . .	..	..	..	+	+	..	+	+	+	+	+	+
— — v. *incudiformis*	..	..	..	..	..	..	..	..	..	..	+	..
27. — *directa*	..	+	..	+	+	+	+	+	+	..	+	+
— — v. *subtilis*	..	..	..	..	..	..	..	..	..	..	..	..
— — v. *remota*	..	..	..	..	..	..	..	..	..	..	..	..
28. — *gelida*	+	+	+	+	..	..	..	+	+	..	+	..
29. — *derasa*	..	..	..	..	+	..	..	+	..	..	..	..
— — v. *erosa*	..	..	..	..	..	..	..	..	..	..	..	..
30. — *detersa*	..	..	..	+	..	..	+	+	+	+	..	+
31. — *Blessingii* . . .	..	..	..	..	..	..	..	..	..	..	..	+
32. — *trigonocephala* .	..	..	..	..	..	..	+	+	..	..	..	+
33. — *recurvata* . . .	..	..	..	..	..	..	+	..	..	..	..	+
34. — *superba*	..	..	..	+	..	..	+	+	+	..	..	..
— — subsp. *sibirica*	..	..	..	..	..	..	+	+	+	+	+	..
— — — *obtusa*	..	..	..	+	..	..	..	..	..	..	..	..
35. — *algida*	..	..	..	+	..	+	..	..	..	..	..	..
36. — *glacialis*	..	..	+	+	..	+	..	+	..	..	..	..
37. — *forcipata*	..	..	..	..	..	..	..	..	..	..	..	..

IMPORTANT SAMPLES FROM THE ICE.

the ice-foot.				Lumps in open channels.									Green ice and snow, Aug. 5, 1894.	Dirt on the ice.	Barents Sea, Aug. 8, 1896.
July 27, 1894.		Aug. 5, 1894.		July 18, 1894.	July 20, 1894.	July 24, 1894.			Aug. 3, 1894.	Aug. 5, 1894.					
N. 81° 15′ E. 125° 25′		N. 81° 7′ E. 127° 30′		N. 81° 26′ E. 125° 10′	N. 81° 30′ E. 125° 10′	N. 81° 24′ E. 125° 1′			N. 81° 5′ E. 127° 19′	N. 81° 7′ E. 127° 30′					
21	22	24	25	1	10	9	19	20	3	23	28	29	26	27	30
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..	..	..	..	..	..	..	..	..	..	+	..	..	..	..	..
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..	..	..	+	+	+	..	..	+	+	+	+	+	..	..	..

TABLE II (continued). **CONTENTS OF THE MOST**

	Water melted from new ice.		Ponds on the ice, not communicating with the sea.				Diatoms on					
Date.	Oct. 18, 1893.	Oct. 20, 1893.	July 22, 1894.	July 24, 1894.			July 20, 1894.		July 24, 1894.			
Locality.	N. 78° 19′ E. 136° 16′		N. 81° 28′ E. 125° 1′	N. 81° 24′ E. 125° 1′			N. 81° 30′ E. 125° 10′		N. 81° 24′ E. 125° 1′			
No. of the sample.	8	6	7	2	5	17	4	11	14	15	16	18
38. *Pinnularia borealis* . . .	..	..	..	..	..	..	..	..	..	..	..	..
39. — *perlucens*	..	..	..	..	..	..	..	..	..	..	..	..
40. — *ambigua*	..	..	..	+	..	..	..	..	..	..	..	+
41. — *quadratarea* . .	..	..	..	..	..	..	..	..	..	..	..	..
— — v. *Stuxbergii*	..	+	..	+	+	..	+	+	..	+	+	+
— — v. *bicontracta*	..	..	..	+	..	..	..	..	..	..	+	..
— — v. *constricta* .	..	..	..	..	..	..	..	..	..	..	..	+
42. — *semiinflata* . . .	..	..	..	..	..	..	+	..	..	..	..	+
— — v. *decipiens* .	..	..	..	..	..	..	..	..	..	+	..	..
— — v. *inæqualis*	..	..	..	..	..	..	..	..	..	..	..	..
43. *Amphora lævis* v. *lævissima*	..	..	..	..	..	..	..	..	..	..	..	+
44. *Fragilaria oceanica* . . .	+	+	+	..	..	..	..	+	..	+	..	..
45. — *cylindrus* . .	+	+	+	+	+	+	..	+	+	+	+	+
46. — *Harrisonii* . .	..	..	..	..	..	..	..	..	..	..	..	..
47. *Surirella Oestrupii*	..	..	..	+	+	..	..	..	..	..	..	+
48. *Hantzschia Weyprechtii* .	..	..	..	..	..	..	..	..	..	..	..	..
49. *Nitzschia denticula*	..	..	..	..	..	..	..	..	..	..	..	..
50. — *hybrida*	..	..	..	+	+	..	..	+	..	..	..	..
51. — *distans*	..	..	+	+	..	..	+	+	..	..	+	+
52. — *Brebissonii* v. *borealis*	..	..	..	..	..	..	..	..	..	..	..	+
53. — *lævissima*	..	..	..	..	..	..	+	+	+	+	+	+
54. — *gelida*	..	..	..	+	..	+	..	..	+	..	+	+
55. — *polaris*	+	..	+	+	..	..	+	+	+	+	+	+
56. — *frigida*	..	+	..	..	+	..	+	..	+	+	*c*	+
57. — *lanceolata* v. *pygmœa*	..	..	..	..	..	..	..	..	..	..	..	..
58. — *acicularis*	..	..	..	..	..	..	..	..	..	..	+	..
59. — *Closterium*	..	..	..	..	..	..	..	..	..	..	..	..

IMPORTANT SAMPLES FROM THE ICE.

the ice-foot.				Lumps in open channels.									Green ice and snow, Aug. 5, 1894.	Dirt on the ice.	Barents Sea, Aug. 8, 1896.
July 27, 1894.		Aug. 5, 1894.		July 18, 1894.	July 20, 1894.	July 24, 1894.			Aug. 3, 1894.	Aug. 5, 1894.					
N. 81° 15′ E. 125° 25′		N. 81° 7′ E. 127° 30′		N. 81° 26′ E. 125° 10′	N. 81° 30′ E. 125° 10′	N. 81° 24′ E. 125° 1′			N. 81° 5′ E. 127° 19′	N. 81° 7′ E. 127° 30′					
21	22	24	25	1	10	9	19	20	3	23	28	29	26	27	30
..	..	..	..	..	..	..	..	..	+	..	..	..	..	..	..
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+	*cc*	+	+	*cc*	+	+	..	*cc*	*cc*	*cc*	*cc*	+	..	..	..
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..	..	..	..	+	..	..	..	..	..	..	..	..	..	..	..

TABLE II (continued). **CONTENTS OF THE MOST**

	Water melted from new ice.		Ponds on the ice, not communicating with the sea.				Diatoms on					
Date.	Oct. 18, 1893.	Oct. 20, 1893.	July 22, 1894.	July 24, 1894.			July 20, 1894.		July 24, 1894.			
Locality.	N. 78° 19′ E. 136° 16′		N. 81° 28′ E. 125° 1′	N. 81° 24′ E. 125° 1′			N. 81° 30′ E. 125° 10′		N. 81° 24′ E. 125° 1′			
No. of the sample.	8	6	7	2	5	17	4	11	14	15	16	18
60. *Chætoceras criophilum* . .	..	+	..	+	..	..	..	..	..	..	..	+
61. — *boreale*	+	+	+	+	+	+	+	..	+	..	..	+
62. — *decipiens* . . .	+	+	+	+	..	+	+	..	..	..	..	+
63. — *Mitra*	..	..	..	..	..	..	..	..	..	..	..	+
64. — *teres*	..	+	+	+	+	..	..	..	..	..	..	+
65. — *contortum* . . .	+	+	+	+	..	+	..	..	..	..	..	+
66. — *diadema* . . .	+	+	+	+	..	..	..	..	..	..	..	+
67. — *debile*	..	+	+	+	+	..	..	..	..	..	..	+
68. — *sociale*	..	+	..	..	..	..	..	..	..	..	..	..
69. — *Wighami* . . .	+	+	..	..	..	..	..	..	..	..	..	..
70. — *furcellatum* . .	..	..	..	..	..	..	..	..	..	..	..	..
71. — *septentrionale*	..	+	..	..	..	..	+	..	..	+	..	..
72. *Xanthiopyxis polaris* . .	..	..	+	+	+	..	+	..	..	..	..	+
73. *Thalassiosira Nordenskiöldii*	+	+	+	+	+	..	..	..	..	..	..	+
74. — *gravida* . . .	+	+	+	+	+	+	..	..	..	..	..	+
75. — *hyalina* . . .	+	+	..	..	..	..	..	..	..	..	..	..
76. *Melosira hyperborea* . . .	..	..	..	+	..	..	*cc*	*cc*	*c*	*cc*	+	..
77. — *crenulata*	..	..	..	+	..	..	..	..	..	..	..	..
78. *Actinocyclus alienus* v. *arctica*	+	+	+	+	..	+	+	..	+	..	+	+
79. *Coscinodiscus oculus iridis*	..	..	+	..	..	+	..	..	..	..	..	+
80. — *polyacanthus* . .	..	..	..	..	..	..	..	..	..	..	..	..
81. — *curvatulus* . . .	..	..	..	..	..	+	..	..	..	..	..	+
82. — *Kützingii* v. *glacialis*	..	..	..	..	..	+	..	..	..	..	..	+
83. — *bioculatus* . . .	..	+	+	..	..	..	..	+	..	+	+	..
84. — *septentrionalis* .	..	..	..	+	+	+	..	+	..	..	+	..

IMPORTANT SAMPLES FROM THE ICE.

the ice-foot.				Lumps in open channels.									Green ice and snow, Aug. 5, 1894.	Dirt on the ice.	Barents Sea, Aug. 8, 1896.
July 27, 1894.		Aug. 5, 1894.		July 18, 1894.	July 20, 1894.	July 24, 1894.			Aug. 3, 1894.	Aug. 5, 1894.					
N. 81° 15′ E. 125° 25′		N. 81° 7′ E. 127° 30′		N. 81° 26′ E. 125° 10′	N. 81° 30′ E. 125° 10′	N. 81° 24′ E. 125° 1′			N. 81° 5′ E. 127° 19′	N. 81° 7′ E. 127° 30′					
21	22	24	25	1	10	9	19	20	3	23	28	29	26	27	30
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
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APPENDIX.

EXTRACTS FROM Dr. H. G. BLESSING'S JOURNAL,

WITH REMARKS BY THE AUTHOR.[1]

June 26th, 1894. "Out on the ice this afternoon to look for algæ. For a long time we sought in vain, but at last on the way back found some green confervæ in a little pool. It proved to be an alga that was growing out of the underlying ice, and reached up to the surface of the water, where the greater part of it was floating. *The part of the alga lying upon the surface of the water* was of a dark green colour, and had air-bladders, while the masses of *tough, slimy threads* that attached it to the underlying ice-foot were of a paler green. When I broke off a piece of the edge on one side of the pool, where it was deeply undermined by the water, there proved to be abundant algæ vegetation here too. There were also some *whitish, translucent algæ,* though few. These seemed to be growing on the under side of quite thin, probably only a few nights old, ice. At any rate they were partly attached to such pieces of ice. During the excursion, I noticed that wherever there were algæ in ponds and channels, there was also a quantity of 'dirty' ice. The idea then occurred to me to experiment with a little of the earth I have gathered upon the ice, to see whether algæ would grow from it. I was confirmed in this idea by finding in places, under

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[1] Dr. *Blessing* has kindly allowed me to make use of the botanical notes that he made on board the *Fram* during the time of the collection of the samples. He has made many interesting observations, especially with regard to the occurrence and colour of the ice-flora, and has drawn a number of forms under the microscope. Those parts of the journal that treat of the occurrence on the ice, are here translated verbatim.

H. H. G.

the water, ice in which there were holes containing algæ mixed with particles of earth. In other places I saw similar holes containing only earth or clayey soil, under the water."

In his entry for the 27th June, Dr. Blessing states that he has examined under the microscope some prepared specimens of the samples that he had collected on the 26th. From the descriptions and drawings, it appears that he has observed the following forms, all with their cell-contents:

Melosira hyperborea, Grun., *Chætoceras septentrionale*, Oestr., *Fragilaria sp.*, *Nitzschia Closterium*, *Nitzschia sp.*, probably *N. lævissima*. *H. H. G.*

July 7th. "Out today with the drag-net after algæ. This time I did not need to go far. In the first pack-ice, I found a place like a well in the middle of the ice, going right down to the sea. Here there were chains of algæ[1] in quantities. I at once recognised the previously observed alga, and here as in the former place, it was the predominant one. It shot up from the underlying ice with masses of greenish red threads. The ice was just discernible far down in the water (about 20 or 25 feet below the surface). In several places this alga had grown right through the ice, which was like a coarse sieve. Earth and such like has probably been lying on the projecting ice-foot. I also saw today some white, floating lumps. Differentiating as well as possible the various kinds of this vegetation, I took 7 samples in envelopes, which I numbered and entered in my note-book on the spot, so as not to confuse them."

On examining them under the microscope, Dr. Blessing found, besides *Melosira hyperborea* which predominated, several other species of the genera *Navicula* and *Nitzschia*. They cannot, however, be identified with certainty from his drawings.

One sample contained almost exclusively *Fragilaria oceanica*. It was "taken from the fine, mobile, disconnected, rust-coloured film, lying in tufts, sometimes in hollows. The place communicates with the sea". Judging from the drawings and from the colour observed, this diatom has also undoubtedly been alive. *H. H. G.*

July 11th. "Was at a place yesterday close to where I found algæ last time. There was an eddy with saltish water, and salt ice formed the bottom of the eddy. It was connected with a piece of open channel beyond. There were numerous dark dots of various sizes on the blue-green ice at the bottom of the eddy. It looked as if clay or earth had melted its way into the ice and formed holes. With a syringe and an india-rubber tube, I took up some of the contents of the holes, and filtered it. In the matter thus gathered,

[1] *Melosira hyperborea*.

the organic life consisted of only a few diatoms and one animal, probably belonging to the Infusoria.

When the summer was so far advanced that there was some plant-life in the water, the sun had already melted so much of the snow and ice, that there was a stratum of brackish water about 1 metre in depth, above the usual sea-water. This water was rather fresh than salt. I am of opinion that this is especially important for the growth of diatoms, as I nearly always (I might say always) saw them floating about in this brackish water, and generally almost exactly at the boundary between the salt and the brackish water. The already-mentioned chain-algæ, on the other hand, which sometimes grew free in the water, from ice lying far below, or hung like a film of cobweb to the ice-walls, evidently throve best in the salt water.

While I think of it, I will mention that both the ordinary algæ and the silicious algæ that I have found, have been as it were enveloped and saturated with mucilage, quite transparent, tough, but not pulling out into threads, so that the whole mass came away as soon as a small piece came beyond the edge. This was especially the case, however, with the algæ that are far more cohesive than the masses of diatoms. When, for instance, I bring up a lump of these diatoms in the net, it is spread over a large portion of the surface of the net when it comes up, while it has kept its globular form fairly well during the careful drawing up of the net through the water. I then generally scrape the net gently with a flat knife, when I cannot turn the mass out of the net."

July 18th. "Out today with Dr. Nansen — I to collect algæ, he to take photographs. The thing was to find a good place with the 'brown snow', or rather 'brown ice'. I have been thinking about this for some time, for all over the ice we can see these more or less dark patches. I have taken samples from numerous places, and found that it is clay, or earth, which, according to its quantity, imparts this colour to the ice. Dr. Nansen says that he has examined a patch of this kind, and found that the colour is due to diatoms. Today again we found one of these places, which Dr. Nansen calls a 'diatom-place'. I have now just examined the sample under the microscope, and found it to consist chiefly of clay, or at any rate inorganic matter,

with only here and there a diatom, not nearly enough to give it a colour. When the ice with this matter in it was melted, I saw at once that it had a tendency to deposit sediment in two layers, and I examined each one separately. In the lower layer there were a number of rather large, irregular grains of felspar."

July 21st. "Was also out today with Hansen to collect algæ. He helped me, with great interest, in the often difficult work of getting up particular accumulations of diatoms, that are often found in holes and cracks far down in the water. On these occasions I use a very long — more than 3½ metres — slender rod to the end of which is attached a glass point with a reservoir behind. A long india-rubber tube is fastened to this and along the rod, and at the upper end of the rod is connected with a syringe. I can thus suck up any particular substance that I have caught sight of under the water. For the ordinary lumps of diatoms and algæ that float about in the water, or grow upon an ice-wall, etc., I use the frequently-mentioned drag-net. This also has a very long handle, and is as light and easily manipulated as possible. The net itself is only about 2 decimetres in diameter, and consists of a thick ring of steel wire, to which a very shallow bag of ordinary white gauze is attached. The net can be adjusted in relation to the handle both horizontally (continuing the direction of the handle) and perpendicularly."

Bottle 4 (No. 17). "Earth and diatoms? Lay like grayish yellow lumps in holes at the bottom of a little pool in the ice, which could not be supposed to communicate with the open sea. I expressly mention this, as it is the first time I have observed such a substance in confined ponds. (It is of course not impossible that the place may formerly have communicated with the sea). The water in these ponds is fairly fresh, containing, when tested by Dr. Nansen with Tornöe's apparatus, only a few tenths per cent of salt. It gives, however, a distinct precipitate — though appearing only as a cloudiness — with $AgNO_3$. Are these then fresh-water diatoms that can stand the salinity, or are they salt-water diatoms that can thrive in brackish water? As I found these upon an ice-surface that betrayed, by the abundance of earth (clay) on it, its former association with land (or river-water), and as, notwithstanding

diligent search, I have never found such a substance in the ponds on the pure — not earthy — greenish blue sea-ice, I am inclined to suppose these diatoms to be fresh-water diatoms which have been brought out into the sea by river-water, or blown out on to the ice, together with earth-particles, etc."

The botanical observations that Dr. Blessing has noted in his journal during the remainder of the summer of 1894, refer especially to the results of his microscopic investigations, while nothing more is communicated about their occurrence than what he has written upon the labels of the bottles.

From his drawings in the journal, I can recognise the following species: *Chætoceras boreale,* (fragments), *Pleurosigma Stuxbergii, Thalassiosira gravida* with spores, *Diploneis didyma, Nitzschia hybrida* (?), *Amphiprora kryophila* with cell-contents, *Fragilaria oceanica* with spores, *Nitzschia frigida* and another *Nitzschia sp.*

He gives drawings, moreover, of some fungus-threads, and in several places mentions an infusorium and motile bacteria. *H. H. G.*

July 16th, 1895. "Was out yesterday afternoon in the boat, in order, among other things, to see whether algæ-vegetation and diatoms were beginning to come in the channels and on the under-water ice. For this purpose, I let the boat drift along the margin of the channel, and carefully examined all small holes, corners, cracks and enclosed pools; for I knew from last year's experience that this rare flora flourished in such places. But I saw only very little, though I persevered for a long time, and examined a very extensive area. I saw here and there signs of the yellowish red, or yellowish brown growth that appeared last summer, like a light, dusty cobweb, upon pretty well every ice-foot, or ice-wall, that was a little old, and which I know to be diatom growths. There was also a small, detached piece of the 'large chain-alga'[1] of last year, floating in the channel.

Aug. 7th. "Was out yesterday to look for algæ, but in spite of long searching, could not find even a trace of botanical substance. (I found however, the same evening, a beautiful *Medusa*)."

Sept. 2nd. "Have been out repeatedly during the past month, for the special purpose of looking for algæ, etc., and I am always telling my companions to keep their eyes open; but I have not yet succeeded in getting hold of a single sample.

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[1] *Melosira hyperborea.*

I cannot understand the cause of this. There has been a great deal of water on the ice this summer as compared with last; but even if I imagine the spores (?) to have been washed away by the streams of water, the growths should surely still be found in the channels? It is not possible to imagine that the winter has been too cold."

Thus the results of the second summer were almost nil, and in the summer of 1896, we began our homeward voyage long before there could be any question of finding fully-developed algæ-vegetation on the ice.

H. G. Blessing.

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PLATE II.

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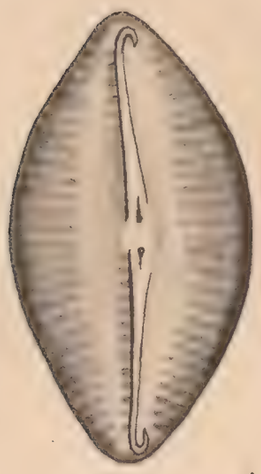
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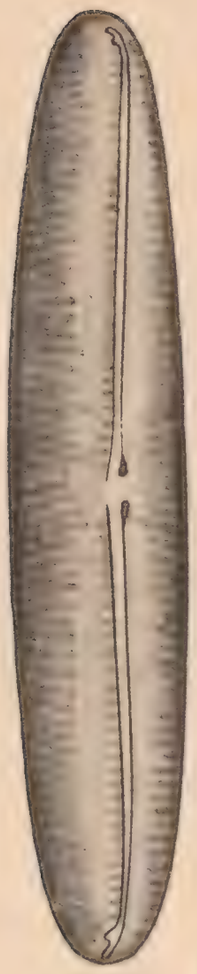
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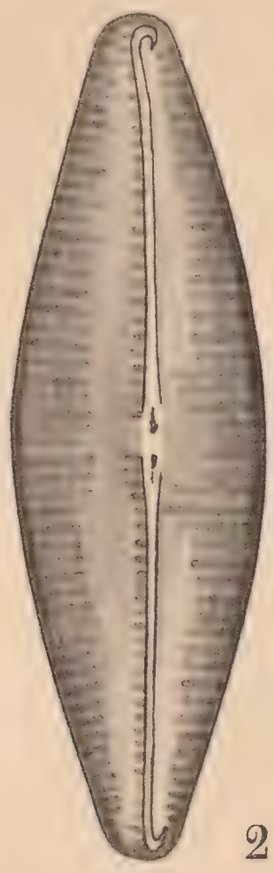
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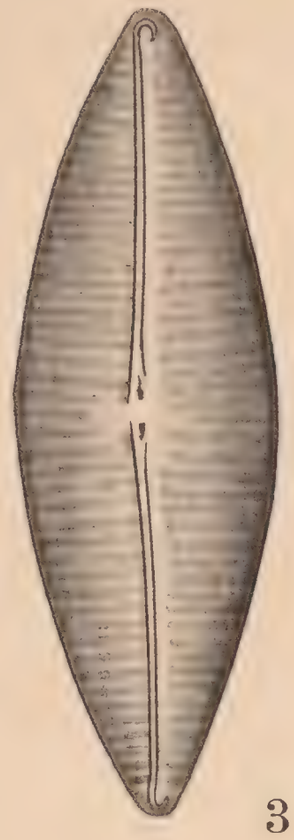
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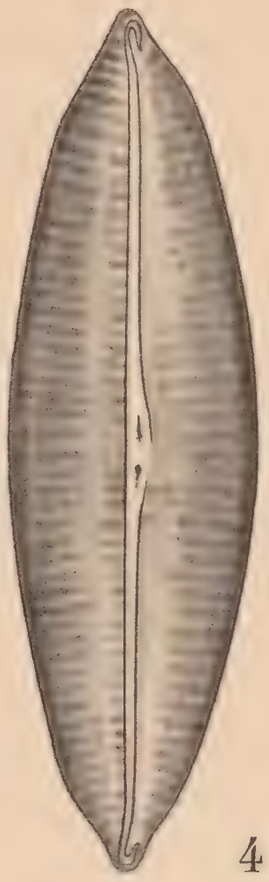
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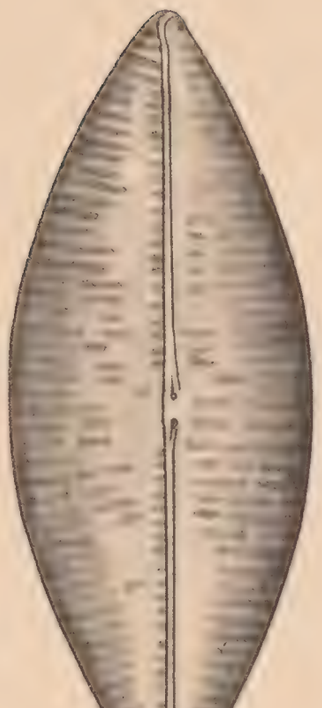
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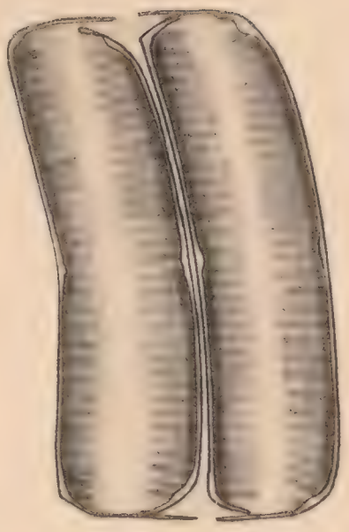
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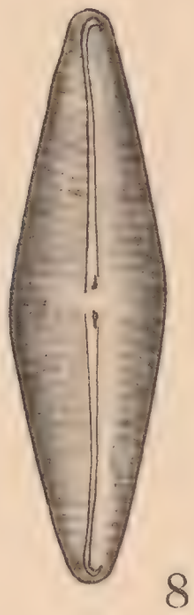
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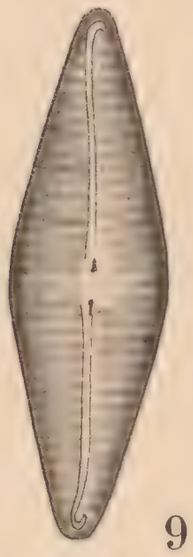
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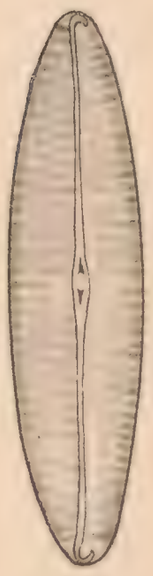
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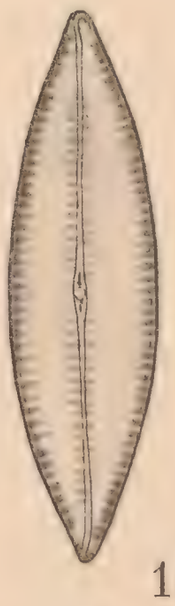
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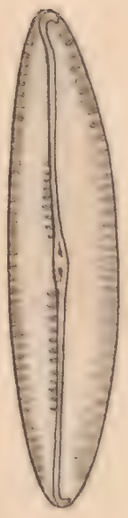
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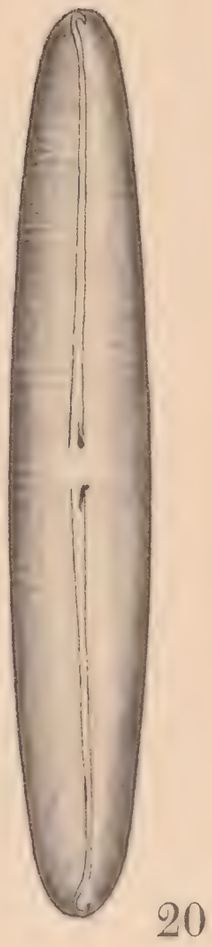
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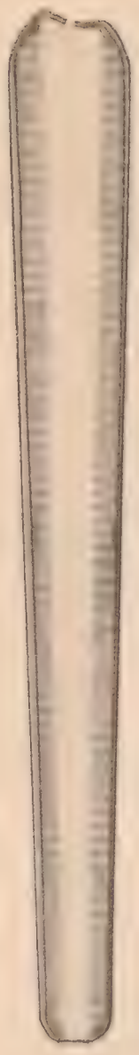
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PLATE III.

PLATE III.

(Where not otherwise stated, the magnification is $\frac{1000}{1}$).

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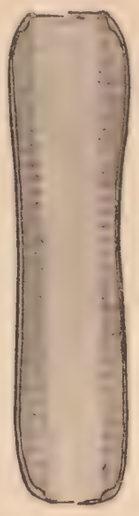

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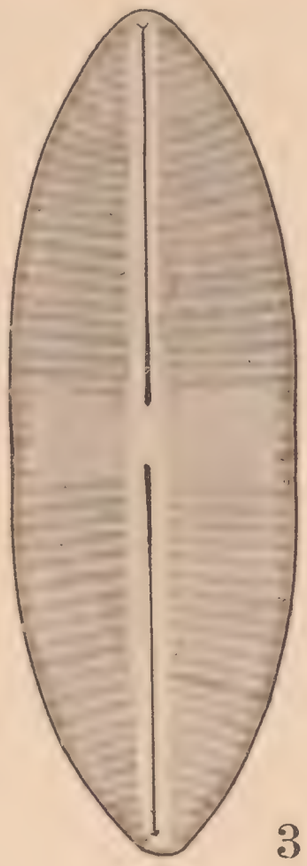

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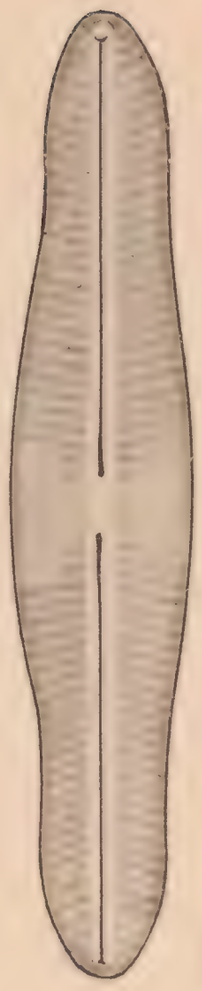

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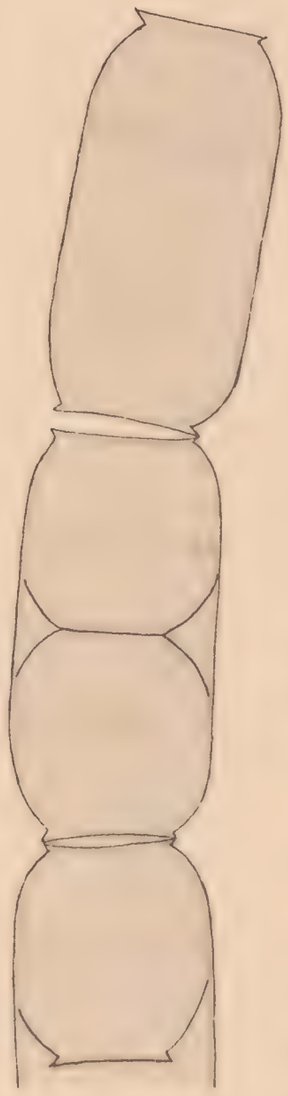

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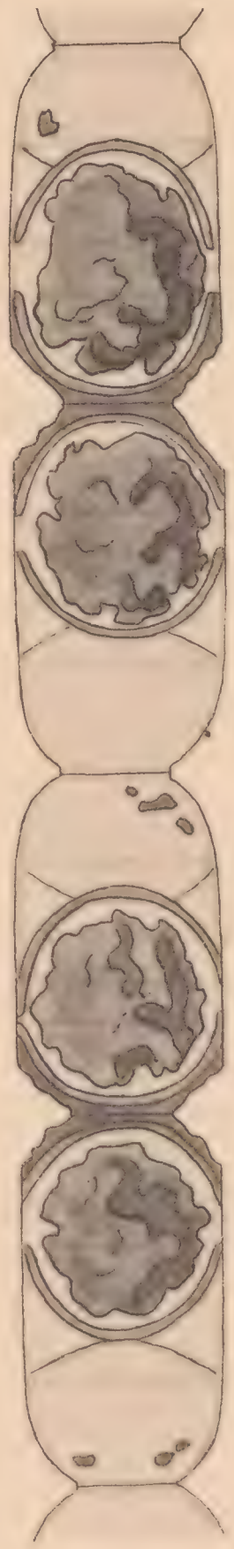

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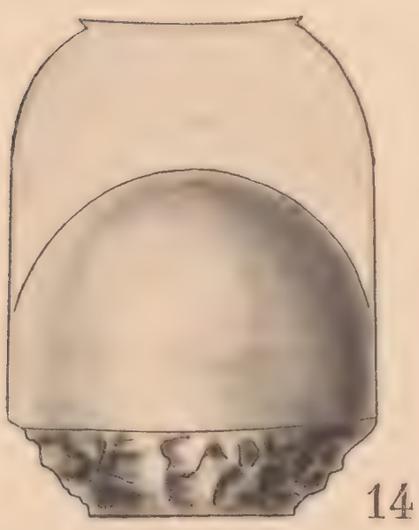

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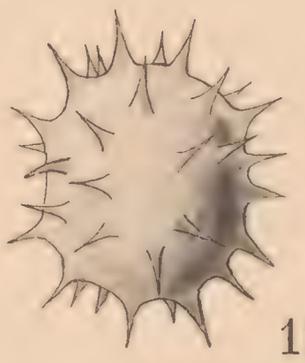

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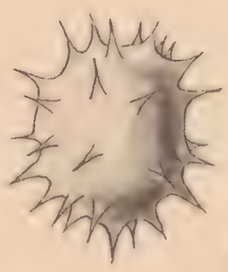

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H. H. GRAN DEL.

PACHT & CRONE PHOTOT.

XII.

THE LOWER SILURIAN AT KHABAROVA

BY

JOHAN KIÆR.

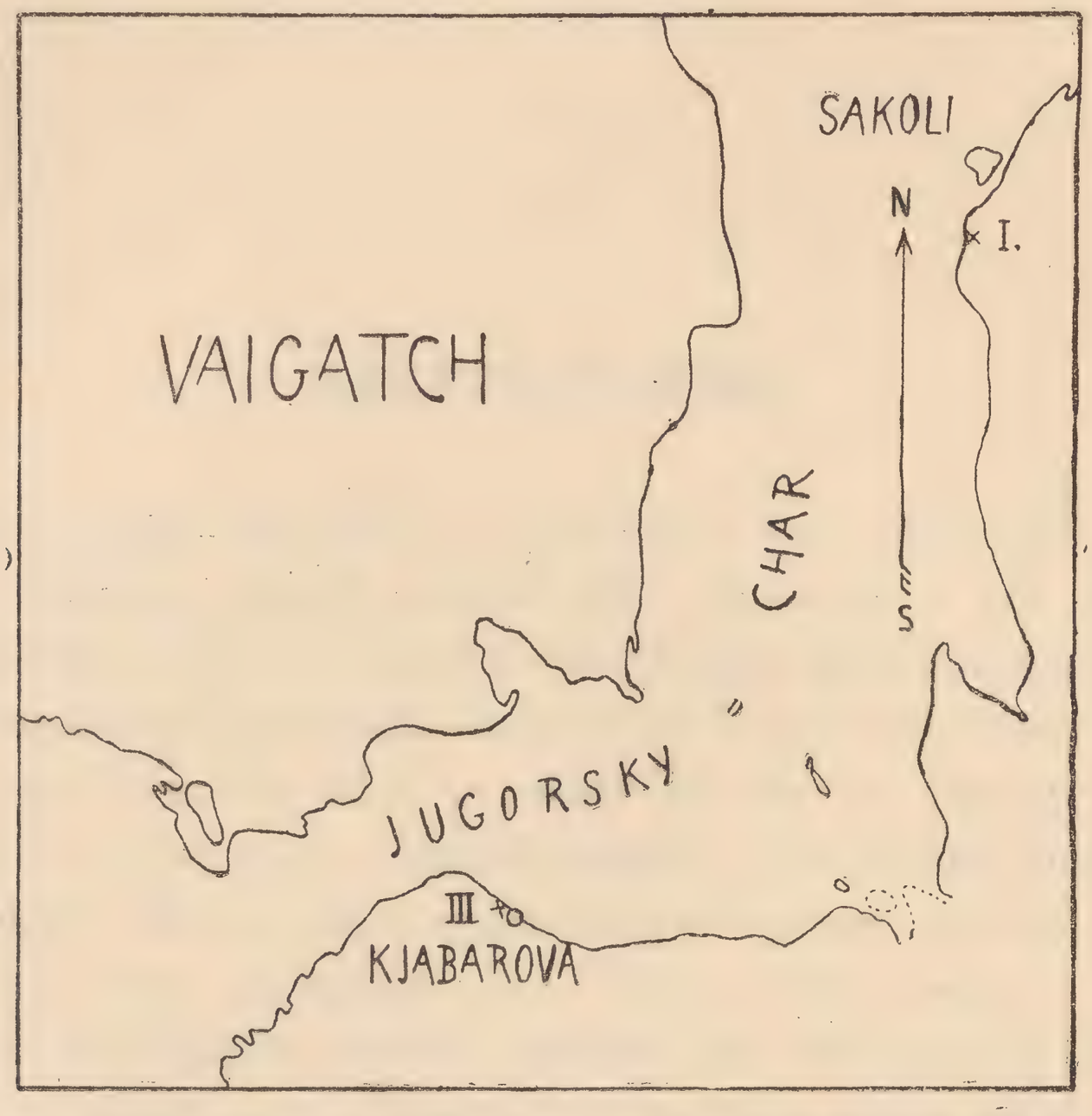
(WITH 1 PLATE.)

INTRODUCTION.

During his stay at Khabarova, on the south side of Yugor Strait, from July 29th to August 3rd, 1893, Professor Nansen discovered in several places fossiliferous strata, which proved to belong to the Lower Silurian formation. After the successful return of the Norwegian North Polar Expedition, Professor Nansen entrusted me with the working up of the material collected. In this work I have been aided by Professor Brøgger in many ways, among which I would especially mention his assistance in determining the Asaphidæ fragments. I would further mention that through the great kindness of Professors Tschernyschew and Lahusen, I had the originals sent me of the Lower Silurian fossils described by Keyserling from Ilytsch in the Ural Mountains. I am also indebted to Professor Tschernyschew for information concerning Russian literature bearing upon my work. To all the above-named gentlemen I here express my thanks, as also to Frøken Sigfrid Bergh for the care and skill with which she has executed the drawings for my work.

Professor Nansen's journal of the stay at Khabarova, with notes made on the spot, profiles, etc. was unfortunately lost in an accident on the Yalmal Coast. The following information concerning the various localities rests upon verbal communications, which, after the lapse of some time, cannot be expected to go very much into details. On the 30th July, Professor Nansen reconnoitred northwards in Yugor Strait. On the east side of the north-eastern opening of Yugor Strait, a little to the south of the Sakolii Islands he found some

badly-preserved fossils in a small rocky promontory near the shore. The locality is indicated on the sketch-map below, from Professor Nansen's recollection.



Sketch of Yugor Strait, with the localities drawn to the scale of 25 mm. to 4 nautical miles. After the map from the Vilkizky Expedition 1898.

On the 1st Aug. he made the most important find. In the rocky point on the shore below Sibiriakoff's storehouse, close to Khabarova, he found a calcareous slate containing numerous fossils. "Strike about SE to NW (Magnetic), and dip about 70—80° SW, but varying somewhat in different places, becoming almost vertical. The shells always lay in a horizontal position, and not in the direction of the strata, but of course almost at right angles to them, which made it a difficult matter to get them out whole". The stratification, in the opinion of Professor Nansen, was clearly schistosity produced by pressure. According to this then, the original stratification should have been horizontal. All the fossils described in my paper are from this locality.

There are also samples of a calcareous sandstone, containing quartz-particles, some of them very coarse. The place where this was found cannot, on

account of the destruction of the original journal, be accurately determined. It was probably in the neighbourhood of the preceding locality.

The fossiliferous strata shown by Professor Nansen to exist at Khabarova are the first undoubted Lower Silurian beds known of in this region.

DESCRIPTION OF THE FOSSILS FOUND.

I.

THE CALCAREOUS SLATE SOUTH OF THE SAKOLII ISLANDS ON THE EASTERN SIDE OF YUGOR STRAIT.

The sediment consists of a rather light greenish gray, irregularly schistose, calcareous slate, which seems slightly metamorphosed. There are numerous fossils, all Brachiopoda; but their state of preservation is so bad, that an exact determination is impossible. All that can be said is that there are several *Orthis* forms, one of which is perhaps identical with the *O.* cf. *parva*, Pand, from Khabarova, described in my paper. Forms such as *Strophomena Nanseni* and *Leptæna sericea*, Sow., which are so common in the last-named locality, are not found in these strata, while two or three other forms seem to be peculiar to them. The kinds of rock too, are not alike in the two places, though this may be due to subsequent change. I consider it probable that the strata in these two localities belong to different zones; but there is nothing to prevent the calcareous schist south of the Sakolii Islands from also being Lower Silurian.

II.

THE CALCAREOUS SANDSTONE, PROBABLY FROM A PLACE IN THE NEIGHBOURHOOD OF KHABAROVA.

Owing to the destruction of Professor Nansen's journal, the locality of this sediment cannot be more exactly determined. It is a hard calcareous sandstone, of a bluish gray colour when freshly broken, and containing quartz-

particles of very various sizes, from quite fine to 3 or 4 millimetres in diameter. The strata are thin. There are only a few traces of indeterminable Brachiopoda. These sediments have been of purely shore formation.

III.

THE CALCAREOUS SLATE FROM A ROCKY POINT ON THE SHORE BELOW SIBIRIAKOFF'S STOREHOUSE, CLOSE TO KHABAROVA.

The sediment consists of a bluish gray, more or less argillaceous, irregular, calcareous slate. Certain portions consist of firmer, purer lime, and are full of fossils; other, often more schistose, parts, contain fewer fossils, generally only the new *Strophomena* form. Here were found the fossils now to be described, which, as I shall subsequently show, admit of an exact determination of age.

1. MONOTRYPA sp.

Two small fragments of discoid *Monotrypa* colonies. They are too imperfect for any further determination.

2. ORTHIS cf. PARVA, Pand. and nov. var. POLARIS.

(Figs. 1—8).

The following table gives the measurements of the best specimens.

No.		Length	Breadth	Thickness	
1	From Khabarova	10·5 mm.	11 mm.	6 mm.	Figs. 6—8
2		9 „	10 „	5 „	
3		7 „	8 „	4 „	
4		8 „	9·5 „	3·75 „	
5		7·5 „	8·5 „	3·5 „	Figs. 1—4
6		6·5 „	8 „	3 „	
7		5 „	6·5 „	2·5 „	
8	A typical *Orthis parva*, Pand, from Volchov.	8 „	9 „	4·5 „	

Some of the specimens, as the first three numbers in the table show, agree well with the typical *parva*, Pand., although they attain greater

dimensions than that form. Others exhibit some difference, the breadth being relatively greater, and the thickness less (Nos. 4—7). I do not think, however, that the latter can be separated as a species of their own. They all certainly belong to the same group, which I regard as a further development of *O. parva,* Pand., and put down as *O.* cf. *parva.* The specimens that are somewhat different I put down as a new variety, *polaris.*

The most important characteristics of this form have already been mentioned in their measurements. The ventral valve is vaulted rather considerably, more especially in the most typical specimens (figs. 5—8), but, particularly in the variety, not so broadly rounded off as in the typical *parva,* Pand., therefore with a narrower back than in that form. There are also, however, quite round-backed ventral valves. The greatest width of the valve is at about the middle, not at the hinge-line. The umbo is sharp and only slightly deflexed towards the hinge; but this seems especially to be the case in the much decorticated specimens. The dorsal valve is comparatively much vaulted behind the hinge, but then sinks anteriorly into a broad, often rather deep curve (figs. 2 & 6). The umbo projects distinctly. In this, as also in the structure of the hinge-surfaces, it agrees well with *parva,* Pand. The curve of the dorsal valve in the latter is perhaps somewhat flatter, but this proportion also varies in the form from Khabarova. The sculpturing seems to agree with that of *parva,* Pand. in the number of ribs, etc.

Occurrence. Especially in the more calcareous parts, in great numbers together with *Leptœna sericea,* Sow.

3. PLATYSTROPHIA BIFORATA, Schl.

The table gives the dimensions of the two best specimens.

No.	Length	Breadth	Thickness
1	14 mm.	17 mm.	10·5 mm.
2	11·5 „	13·5 „	7 „

As the measurements show, this is a comparatively slight variation of this widely-distributed form. There are 4 strong ribs on the fold, 3 on the sinus, and 7 on the wings. Compared with Norwegian variations, it most resembles that occurring in stage 4b; and it has not yet been found lower

than that in Norway, though in Esthonia it is found on the same horizon as *Megalaspis planilimbata, Meg. limbata,* and *Asaphus priscus* (B II α, Lamandry [1]).

I have found only 3 specimens in my material.

4. **STROPHOMENA NANSENI**, nov. sp.

(Figs. 9—18)

There are about 25 more or less imperfect shells and shell-impressions of this form among my material. None are quite perfect, but together they give a complete idea of its external form and sculpturing. There is, on the other hand, hardly anything to be seen of its internal structure.

The following table gives the dimensions of the 3 best specimens.

No.	Length	Breadth (at hinge-line)	Convexity of Valve	Thickness of both Valves	
1	40 mm.	40 mm. (?)	8 mm.		Fig. 13, only ventral valve, angle imperfect.
2	32 „	40 „ (?)	5 „	4 mm.	Figs. 16 & 17, both valves, but somewhat imperfect.
3	17·5 „	19 „	2 „		Fig. 9, only ventral valve, angle perfect.

The proportion between the length and breadth of the shell varies greatly; the length is either about the same as the breadth (No. 1), or considerably less (No. 2). The hinge-line of the ventral valve forms a very obtuse angle, that of the dorsal valve is straight. The sides and front margin of the valve are broadly rounded, and its greatest width is at the hinge-line, the angles being produced (figs. 9, 11 & 15; figs. 12, 13, 16 & 17 have imperfect angles).

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[1] Wl. Lamandry, 'Neue Beiträge z. Vergleich. d. Ostbaltischen u. Skandinav. Unter Silurs', Centralbl. f. Mineral. 1901. No. 20, p. 612.

The ventral valve is slightly, but regularly, vaulted, with the greatest convexity a little behind the middle of the valve, while the produced angles are flatter. The umbonal region is distinctly elevated, without, however, projecting over the hinge. The dorsal valve is more or less concave, most so just in front of the middle of the hinge-line; it is sometimes nearly flat. The sculpturing consists of close, regular, distinctly-marked main ribs, and between these generally 3 of extreme fineness. In the middle of the valve, in a space of 10 mm. may generally be counted 12 main ribs; and the main ribs issuing from the umbonal region often branch 2 or 3 times, so that at the margin there are from 3 to 7 main ribs between the two original ones. Across these radiating ribs run exceedingly fine, concentric ribs, about 14 or 15 in 2 mm. This produces, on a well-preserved valve-surface, an extremely delicate and beautiful sculpture (fig. 18). Both valves generally exhibit a few concentric lines of growth, generally rather irregular; at the hinge they curve outwards in the form of irregular wrinkles, that are more distinct here than elsewhere on the shell. They seem to be more strongly marked on the dorsal valve than on the ventral. The hinge-area is very narrow, concave, and somewhat curved. The distance between the umbones does not exceed 1 mm. in specimens of a medium size. Both the deltidial spaces appear to be closed. The internal structure cannot be seen.

A few of the specimens seem to have attained still greater dimensions than those given above. I have, for instance, an almost flat dorsal valve that is 47 mm. broad, and at least 36 mm. long. All the specimens, as already mentioned, are imperfect; but those shown in figs. 9, 11 & 15 have at any rate one angle perfect. Fig. 15 shows a dorsal valve of rather different form; but as it is evidently deformed and broken, its original convexity cannot easily be determined.

As the structure of the hinge-area is still imperfectly known, and nothing could be seen of the interior of the shells, the position of this form in the family *Strophomenidæ* cannot be determined with certainty. It has the general form that characterises *Rafinesquina,* Hall & Clarke, and probably belongs to that genus. In external form and sculpturing it resembles *Rafinesquina alternata,* Conrad; but the structure of the hinge-area and a few other characters are different. It seems to be more nearly related to a form that occurs in stage 3c γ in Norway, and which has been called by Brøgger *Strophomena*

imbrex, Pand. var. confr. *semiglobosa*, Dav.[1] No sufficiently good specimens of this form have been found, however, to enable this to be decided exactly. Several points of dissimilarity can be demonstrated, however, so that these 2 forms cannot in any case be united. As regards Davidson's *semiglobosa*, there is certainly no near relationship between it and either the Norwegian form or that described above; and it belongs to altogether different zones. *Strophomena imbrex*, Pand. is quite different.

I have called this new and beautiful *Strophomena* form *Strophomena Nanseni*, after the leader of the Norwegian North Polar Expedition.

Occurrence. Very common, especially in the looser, irregularly schistose parts. It is the brachiopod most characteristic of this occurrence.

5. LEPTÆNA SERICEA, Sow.

(Figs. 19–23).

A flat variety of this widely-distributed form is found in large quantities in the more calcareous parts, together with *Orthis* cf. *parva*, Pand. They accord well with specimens from the American and Norwegian Lower Silurian. The Esthonian specimens that I have from Kuckers and Wesenberg, are much more vaulted. (See the figures).

6. TORELLELLA sp.

(Fig. 24).

There are only 2 specimens in my material, both almost valveless. In the best — which is figured — the pointed end seems to be almost entire, though that part of the specimen is in a poor state of preservation. The length is 11mm. and the width at the broader end 0·9 mm. The valve at first increases rather rapidly in breadth, afterwards very slightly; and it is at first somewhat curved, afterwards almost straight. A transverse section is elliptical, flatter towards the point than at the broader end. The two sides appear to be exactly alike. The shell has been covered with fine transverse ribs; but they are only visible on a small space (fig. 24); beyond it the shell is missing.

[1] W. C. Brøgger, 'Die silurischen Etagen 2 und 3', p. 50.

This form greatly resembles the *Torellella tænia*[1] from Chasmopskalken, Mösseberg, west Gothland, described by Holm; but the Swedish form is much larger, and is said to be quite straight. My specimens, however, are too imperfect to warrant my setting up a new species.

7. MEGALASPIS sp.

(Figs. 25, 26).

There is rather more than half a shell-less pygidium, from which the whole may be reconstructed; but the articular portion is altogether wanting. There are also two or three still smaller fragments of pygidia, and 2 very imperfect body-segments.

The contour of the pygidium is semi-elliptical, the length somewhat exceeding ⅔ of the width. The lateral margins are slightly rounded, and the posterior end considerably so; the anterior margin is almost straight, with a projecting arch for the broad axis. The axis is flat, slightly defined, and unusually broad in front, measuring at its anterior margin ⅓ of the entire width of the pygidium. It tapers towards the back in a curve that is especially rapid at first, so that at the back it is only ¼ the width of the anterior margin. It is also more sharply defined here than farther forward; it ceases close to the marginal band. Segmentation is altogether wanting, or can at any rate only be seen with the greatest difficulty. The limbs are first slightly arched, and then sink rapidly towards the margin in a well defined marginal band, which is about 7 mm. broad (6 mm. in projection) in the hinder portion, and somewhat narrower in front. The facets are broad and very prominent; the marginal grooves are well marked, and run almost straight down to the margin. With the exception of these, the limbs of the pygidium, as also the axis, are almost perfectly smooth; but in a certain light, the last remains of segmentation may be seen in the shape of 6 fine, somewhat curved lines running from the axis down to the marginal band.

The incurved fascia is of the width of the marginal band, is distinctly grooved, and has the usual striation. The sculpturing of the shell cannot be seen.

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[1] Holm, 'Sveriges Kambr. Silur. Hyolithidæ och Conularidæ', 1893, p. 149, Pl. III, figs. 59–62.

One of the two fragments of body-segments, which probably belong to this form, I have had figured. It shows about half a body-segment seen from within (fig. 26). Its outer part is presumably quite imperfect.

The dimensions of the pygidium are: length 26 mm., width 36 mm., width of axis at the anterior margin 12 mm., its length 19·5 mm., width of marginal band 7—6·5 mm.

The form of the incurved fascia and the entire structure of the pygidium show that this is a true *Megalaspis,* while its peculiar axis, the almost complete absence of segmentation, and the sharply-defined marginal band, separate it widely from all the species of this extensive genus with which I am acquainted. It is perhaps most nearly allied to *Megalaspis patagiata,* Tqu., although it cannot in any way be united with that form. In the American Lower Silurian also, there occur forms that are perhaps related, e. g. *Asaphus* (?) *obtusus*, Hall, and *A. marginalis*, Hall[1], both occurring in the Chazy Limestone.

8. **ASAPHUS** sp.

(Figs. 27, 28).

In addition to the above-described, comparatively well-preserved pygidium of a *Megalaspis* sp., there is, in the same piece, a fragment of a pygidium of a small *Asaphus* form. It is not perfect enough to allow of an accurate reconstruction from it of the entire pygidium; but with the assistance of Professor Brøgger, I have drawn a reconstruction of it, in order to give a better idea of its probable form (fig. 28).

In the fragment may be seen the anterior part of the axis with the anterior groove, and 6 or 7 distinctly-defined segments, of which the hinder contour-line is curved, the flat limb with only very indistinct segmentation in the form of a few faint lines, the broad anterior marginal groove, and the proximal portion of the sharply-defined marginal rib in front of it. Lowest down to the left, the outer margin of the limb itself is also visible for a short distance, so that the extreme limits of the pygidium can thereby be approximately determined. On the hinder fracture-surface the incurved fascia can be distinctly traced almost up to the axis.

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[1] J. Hall, 'Palæontology of New York', I, p. 24, Pl. 4 bis, figs. 14 & 15.

It is practically impossible to determine the species from this little fragment All that can be said is that similar small *Asaphus* forms are found on the *Asaphus platyrus* zone in Scandinavia. For a determination of zone this fragment is very important.

9. **ASAPHUS** sp. (?).

An imperfect glabellum, about 3 mm. in length, was unfortunately so broken during preparation, that it can neither be determined with any certainty, nor figured. It belongs without doubt to a very small (young ?) specimen of some asaphid or other.

10. **REMOPLEURIDES** sp.

(Figs. 29, 30).

There is only the cast of about half a head. Unfortunately most of the lingulate projection is missing, but on the other hand the free cheek has been preserved.

The fragment is too imperfect to allow of a determination of the species, as neither the breadth of the glabellum, nor the breadth and shape of the lingulate projection can be decided with any certainty. The glabellum is arched; the tongue appears to have been broad. The eye-lobe is rather broad at the back, and quite narrow in front. The eye is of the usual form, though somewhat broader in front than at the back. Beneath the eye runs a narrow raised band. The free cheek is narrow, obliquely placed, and apparently forms a regular curve, though its posterior part cannot be exactly determined. Its surface is distinctly striated, the striæ running parallel with the margin. For the dimensions, the reader is referred to the figures.

Of all the *Remopleurides* forms with which I am acquainted, *R. nanus*, Herzoz v. Leucht, seems to be the one most nearly allied to the present form. It occurs in Esthonia in C, and in Norway there is a nearly-allied form in 4 b α. I cannot, however, from the above fragment, refer it to this species, especially as the gena in *R. nanus* has not, as far as I know, been described. A movable gena of the Norwegian form, that is in the Christiania University Museum, does not seem quite to agree with the piece here described.

Together with *Leptæna sericea*, Sow. and *Orthis* cf. *parva*, Pand.

GENERAL RESULTS.

It is only of the fossiliferous strata that Professor Nansen found in Khabarova itself, below Sibiriakoff's storehouse, that the age can be exactly determined. I have succeeded in demonstrating the occurrence of the following forms in the material brought thence:

1. *Monotrypa* sp.
2. *Orthis* cf. *parva*, Pand.
   and nov. var. *polaris*.
3. *Platystrophia biforata*, Schl.
4. *Strophomena Nanseni*, nov. sp.
5. *Leptæna sericea*, Sow,
6. *Torellella* sp.
7. *Megalaspis* sp.
8. *Asaphus* sp.
9. *Asaphus* sp. (juv.) ?
10. *Remopleurides* sp.

It is at once clear that this fauna is Lower Silurian; it is only the question as to which zone in this group it belongs to, that requires further solution.

I will first go through the Brachiopoda, which occur in the greatest quantity, and, as regards the number of specimens, form the main part of the fauna. I have set forth above that the *Orthis* form must be regarded as a further development of *Orthis parva*, Pand., which belongs to the *Megalaspis planilimbata* and *Asaphus expansus* zones. *Strophomena Nanseni* is without doubt a new species, but, of the *Strophomena* forms with which I am acquainted, most nearly resembles that called by Brøgger cf. *imbrex* Pand. var. *semiglobosa*, Dav., and found in Norway in stage 3 c γ; it is perhaps a further development of this. *Leptæna sericea*, Sow. and *Platystrophia biforata*, Schl. indicate more particularly zones above the Vaginate Limestone, although this is found lower down in Esthonia. Judging from this find, I should be inclined to put the horizon immediately above groups B in Esthonia, and stage 3 c in Norway. The correctness of this is confirmed in

the most decided way by the trilobites found. They do not, it is true, occur in large quantities, but on the other hand they are of far greater importance than the brachiopods in an exact determination of age in the Lower Silurian. It is a generally experienced fact that in this very period the trilobites are more confined to certain horizons than the brachiopods. The reason of this must be that the trilobites were just then undergoing a rapid development and differentiation, which has resulted in a quick succession of characteristic forms. Two of the trilobites found are especially important, viz. *Megalaspis* sp. and *Remopleurides* sp. The first of these, which is particularly characteristic of Scandinavia and Esthonia, but also occurs in a few forms in North America, first appears in the upper part of the Phyllograptus Slate, attains its highest development in the sediments corresponding to B in Esthonia, and dies out in the *Asaphus platyurus* zone (C_1 a in Esthonia, Platyurus Limestone in Sweden, 4 a α in Norway). *Remopleurides*, on the other hand, first appears everywhere in the same horizon as *Asaphus platyurus*, developing upwards in the Lower Silurian, and dying out with it. A *Remopleurides* has never, to my knowledge, been found lower down, nor a *Megalaspis* higher up. *The Silurian strata at Khabarova itself are thus determined with great certainty as answering to the Asaphus platyurus zone, C_1 a in Esthonia, 4 a α in Norway.* The occurrence of a small pygidium of an *Asaphus* sp. further confirms the correctness of this determination. *Torellella* sp. and *Monotrypa* sp. are of little value in a determination of age.

I was originally inclined to suppose that the Lower Silurian fauna discovered by Keyserling[1] in 1843 near the Ilytsch, a tributary of the Petschora, was of the same age as the above-described forms. The old descriptions and figures were insufficient to decide this question. After having had an opportunity afforded me, through the kindness of Professor Tschernyschew and Professor Lahusen, of studying Keyserling's originals, I have been able to decide with entire certainty that these two faunas are from different zones. I consider the Ilytsch fauna to be somewhat more recent than that of Khabarova.

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[1] Murchison, Verneuil & Keyserling, 'Russia and Ural Mountains', I, 1845, p. 408.
Keyserling, 'Wissensch. Beobachtung auf Reise in Petschoraland', 1843, pp. 363, 364; 1846.
Schrenk, 'Reise durch die Tundren d. Samojeden zum Arktischen Uralgebirge', 1854, II, p. 61.

Another circumstance that I would particularly mention here is that this Lower Silurian fauna at Khabarova is of a marked Scandinavian-Esthonian type. It is no more closely connected with the North American Silurian than is the Scandinavian-Esthonian itself. This will be so evident from the remarks that I have added to the descriptions of the separate forms, that it is unnecessary for me to give any further proofs.

From the other fossiliferous strata found by Professor Nansen in Yugor Strait, there are only some very badly-preserved and imperfect fossils. A determination of their age cannot be made with any certainty; and vague suppositions have little or no value. Nor will the material I have to work upon allow me to discuss the significance of the results shown above in the geology of the arctic Ural Range — still less as the notes made by Professor Nansen on the spot have been lost. One thing, however, is certain, namely that the theory of the most recent Russian research regarding the geology of these northern regions, must be changed in several points. I will only mention that the „Carte Géologique de la Russie d'Europe", 1893, shows only Devonian strata both north and south of Yugor Strait. To what extent the Silurian enters into the geological formation of these regions must be left to future investigations to decide. In the mean time, every horizon positively determined is of the utmost importance in solving this question. The fact that at any rate a Lower Silurian zone can be accurately determined by Professor Nansen's collections, is an important contribution to the geology of these arctic regions; and our exceedingly scanty knowledge of the distribution of the Silurian ocean over the enormous land-area lying between the Scandinavian-Esthonian and the North American Silurian, is thereby carried on a step in advance.

CHRISTIANIA; *Nov. 24th, 1901.*

JOHAN KIÆR.

EXPLANATION OF THE FIGURES.

EXPLANATION OF THE FIGURES.

Figs. 1—4. *Orthis* cf. *parva*, Pand. nov var. *polaris*. Slightly enlarged.

1. Ventral valve.
2. Dorsal valve.
3. Seen from above.
4. Seen from the side.

Figs. 5—8. *Orthis* cf. *parva*, Pand. Slightly enlarged.

5. Ventral valve.
6. Dorsal valve.
7. Seen from above.
8. Seen from the side.

Figs. 9—18. *Strophomena Nanseni*, nov. sp.

9. Small ventral valve. Natural size.
10. Profile of the same.
11. Somewhat obliquely-compressed ventral valve. Natural size.
12. Dorsal aspect of a specimen with part of the hinge entire. Natural size.
13. Large ventral valve. Natural size.
14. Profile of the same.
15. Somewhat flattened impression of a dorsal valve with very marked folds. Natural size.
16. Large specimen; ventral aspect. Natural size.
17. Ditto; dorsal aspect. Natural size.
18. Sculpturing of the ventral valve. Enlarged about 4 times.

Figs. 19—23. *Leptœna sericea*, Sow.

19. Ventral valve. Somewhat enlarged.
20. Dorsal valve. " "
21. Sculpturing of the ventral valve. Enlarged about 4 times.
22. " " " " " " " " "
23. The previously figured specimen, viewed from above.

Fig. 24. *Torellella* sp. Enlarged about 3 times.

Figs. 25, 26. *Megalaspis* sp. Natural size.

25. Pygidium.
26. Part of abody-segment.

Figs. 27, 28. *Asaphus* sp. Natural size.

27. Fragment of a pygidium.
28. Reconstruction of ditto.

Figs. 29, 30. *Remopleurides* sp. Natural size.

29. Glabellum with gena attached; viewed from above.
30. Ditto; lateral aspect.

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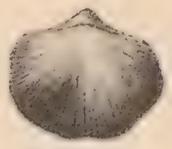

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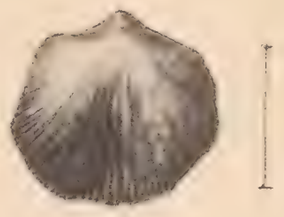

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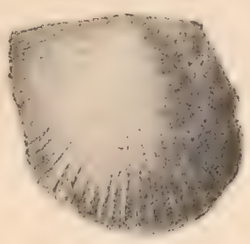

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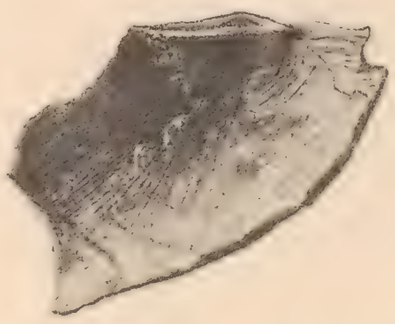

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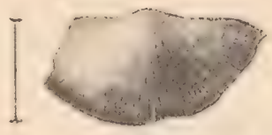

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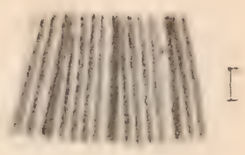

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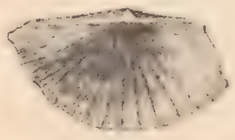

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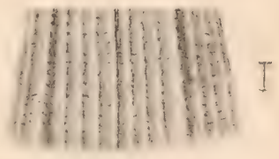

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Sigfrid Bergh del.

Meisenbach Riffarth & Co., München.

XIII.

THE BATHYMETRICAL FEATURES OF THE NORTH POLAR SEAS

WITH

A DISCUSSION OF THE CONTINENTAL SHELVES AND PREVIOUS OSCILLATIONS OF THE SHORE-LINE

BY

FRIDTJOF NANSEN

(WITH 29 PLATES).

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I. INTRODUCTION.

Before starting on our expedition, I fully believed that the unknown North Polar area was more or less covered by an extensive sea, and my opinion was, for instance, that Greenland ended "not very far north of the latitude already reached, and Franz Josef Land" was "probably only a group of islands."[1] The plan of the expedition was in fact based on these assumptions. But in accordance with most geographers, I expected this North Polar Sea to be for the most part comparatively shallow, its area being a continuation, towards the north, of the Eurasian and American continents. And although I assumed that a somewhat deeper channel might extend from the deep sea between Spitsbergen and Greenland, north of Spitsbergen and the Franz Josef archipelago, towards the sea north of the route of the Jeanette[2], I did not expect the depth of this channel to be very great. The greatest depth observed during the Jeanette expedition was only about 80 fathoms. As the Fram was heavily laden, I did not consider it right to encumber her very limited space with the equipment necessary for sounding in very deep water. For soundings we therefore only carried some simple hand-winches, 200 m. bronze wire line, which was also used for the water-bottle, about 1200 m. single steel cord, and about 1900 m. hempen line. We also carried a Rung's bathymeter and several leads of various sizes, some of them, weighing 50 kilogrammes, being provided with special brass tubes (with valves)

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[1] Nansen, How can the North Polar Region be crossed? *Geographical Journal*, London, 1893, vol. I, p. 3.

[2] Cf. Nansen, *Naturen*, Bergen, 1890, p. 14.

for taking bottom-samples. The tubes were of a similar construction to those used by several previous deep-sea expeditions, and had a slide on one side, which could be removed so that the stratification of the sample inside the tube could be seen without removing the sample.

During our drift across the North Polar Basin we soon discovered that our arrangements for sounding were not sufficient for the great depths met with, and we could not even reach the bottom with our line. New line had therefore to be made, one of the ship's thick steel-wire cables having to supply the material for this purpose. The making of the line was rather an arduous piece of work. A ropery had to be extemporised on the ice, where the temperature at the time was very low. The cable had first to be unlaid into its separate strands and then two or more of these strands twisted together by hand. As the cable was only about 50 m. long the single strands had to be twisted together at the ends, and soldered with great care. The first piece of line was made of two strands, the next of three, and the last (upper) piece of four strands. In this manner the men of the Fram managed, after many days' work, to make a fairly good sounding-line, 4450 metres long, which, however, had to be handled very carefully to prevent breaking; and we had to be cautious in this respect, as there was not much more material for making a new line. One difficulty was to get leads that were sufficiently heavy to indicate distinctly when the bottom was reached. A very effective slipping arrangement was constructed, and slipping leads were made out of worn-out fire-bars from the boiler furnaces, with a total weight of up to 30 kilogrammes. We nevertheless failed to notice exactly when the bottom was struck; too much line was let out, kinks formed, and much line was lost. After several failures of this kind, we resolved not to risk the loss of more cord, and chose to arrange our soundings in a safer, although much slower, manner. To the end of the steel cord was attached a hempen stray-line, from 100 m. to 400 m. long, with a lead of about 6 kilogrammes and a tube for taking a bottom-sample. If, for instance, we knew that the depth was, at any rate, not less than 3300 m., we would first let out that length of line, and then haul up. As this was rather heavy work, all hands on board had to join, and two gangs were formed as illustrated in 'Farthest North', vol. I, opposite p. 396. A single sounding would thus take at least half a day. If the tube of the lead was empty when it arrived at the surface, we then let as much more line

run out as the hempen stray-line was long, and then hauled up. In this way we could be certain that the steel line would not kink, even if the lead struck the bottom too early. This operation was repeated, letting out additional, line, *e. g.* 200 m., each time, until the lead came up with a bottom-sample. If, for instance, we found no bottom at 3800 m., and bottom at 4000 m., we would let out 3900 m. and getting a sample also from this depth, we could say with an accuracy of $\pm$ 50 m. that the depth was 3850 m. I considered such a degree of accuracy to be sufficient for this part of the Ocean. As the same sounding-line had also to be used for taking temperatures and water-samples, it became much worn; and as it moreover became rather brittle in the cold air when ice was being rapidly formed upon it, soundings could not unfortunately be taken very often. Capt. Sverdrup, having lost part of the line, had to content himself, as a rule, during the latter part of the drift, with ascertaining that the bottom was not reached at 3000 m.

II. SOUNDINGS.

The following table gives the soundings taken during the expedition.

A line and a dot above the figures *e. g.* $\dot{\overline{400}}$, in the 4th and 5th columns indicate that no bottom was found.

1. SOUNDINGS DURING THE VOYAGE IN OPEN WATER.

Date and Hour.	North Lat.	East Long.	Soundings in Metres.	Soundings in Engl. Fath.	Remarks.
1893.	° ′	° ′	·	·	
July 22, 11.15 pm.	70 43	39 20	200	109	
— 23, 9.15 pm.	71 1	43 38	130	71	Soft mud.
— 24, 3 pm.	71 13	46 50	163	89	Clayey mud.[1]
— 24, 10 pm.	71 17	48 22	130	71	Clayey mud.[2]
— 24, 10 pm.	—	—	130	71	[3]
— 25, 3 am.	71 19	48 52	130	71	Mud.
— 25, 9 am.	71 22	50 6	128	70	Mud.[4]
—	—	—	126·5	69	
— 25, 6 pm.	71 23	51 36	70	38	
— 27, 0.20 pm.	69 43	54 23	50	27·3	Sandy bottom.[5]
— 28, 6 am.	69 28	56 30	24	13·2	
— 28, 0.30 pm.	69 25	57 7	24	13·2	Sand.[6]
— 28, 2 pm.	69 24	57 13	24	13·2	[7]
— 28, 7 pm.	69 24	57 15	23	12·7	[8]
— 28, 9 pm.	69 23	57 17	22	12	Fine sand.[9]
— 29, 4 am.	69 22	57 40	25	13·7	
— 29, 5 am.	69 21	57 54	25	13·7	
— 29, 8 am.	69 24	58 9	27	14·8	
— 29, 9.45 am.	69 33	58 20	30	16·4	Fine sand.
— 29, 3.30 pm.	69 32	59 54	16	8·8	Sand?
— 29, 7 pm.	Khabarova	Harbour.	9	5	
Aug. 4, 9,30 am.	69 53	61 47	82	45	
— 4, 10 pm.	69 43	63 40	30	16·4	
— 4, 12 pm.	69 38	64 0	17	9·3	
— 5, 1 am.	69 35	64 16	18	9·8	
— 5, 2 am.	69 33	64 27	16	8·7	
— 5, 4 am.	69 28	64 50	16	8·7	
— 5, 0·15 pm.	69 37	66 15	25	13·7	Clay.
— 5, 2·30 pm.	69 42	66 21	20	11	
— 5, 3·45 pm.	69 43	66 24	17	9·3	
— 5, 12 pm.	69 43	66 44	15	8·2	
— 6, 1 am.	69 42	66 44	14	7·7	
— 6, 2 am.	69 42	66 43	15	8·2	[10]
— 6, 4 am.	69 40	66 42	16	8·7	
— 6, 5 am.	69 39	66 42	15	8·2	
— 6, 6 am.	69 37	66 42	11	6	[11]
— 6, 8 am.	—	—	11	6	[11]
— 11, 1 am.	70 53	66 3	13·5	7·4	
— 11, 1·30 am.	70 55	66 3	13·5	7·4	
— 11, 2·30 am.	70 58	66 4	14	7·7	
— 11, 3·30 am.	71 2	66 5	14	7·7	
— 11, 5 am.	71 6	66 6	15·5	8·5	

[1] Rung's bathymeter was used.
[2] Rung's bathymeter was used. Bottom-sample preserved.
[3] Ordinary lead was used.
[4] Rung's bathymeter was used. The next sounding was taken with the water-bottle.
[5] This and previous sounding was taken with the water-bottle.
[6] Current running E ᵇ N (magnetic) about 1 knot.
[7] Same current as above.
[8] Current running about W (magnetic).
[9] Water-bottle.
[10] Drifting slowly with the ice.
[11] Moored to a grounded hummock off Yalmal Coast.

Date and Hour.	North Lat.	East Long.	Soundings in Metres.	Soundings in Engl. Fath.	Remarks.
	° ′	° ′			
Aug. 11, 6 am.	71 10	66 7	17·5	9·6	
— 11, 8 am.	71 18	66 10	25	13·7	
— 11, 10 am.	71 21	66 15	27	14·8	
— 11, Noon.	71 22	66 17	26·5	14·5	Water-bottle.
— 11, 2 pm.	71 23	66 18	20	11	
— 11, 4 pm.	71 26	66 36	14	7·7	
— 11, 4.30 pm.	71 28	66 42	9	5	
— 11, 4.45 pm.	71 29	66 45	9	5	
— 11, 5 pm.	71 30	66 47	10·5	5·8	
— 11, 5.30 pm.	71 31	66 48	12.5	6·9	
— 11, 8 pm.	71 36	66 56	16	8·8	
— 12, 4.30 am.	71 57	67 49	30	16·4	
— 12, 6.30 am.	72 4	68 6	20	11	
— 12, 7.30 am.	72 8	68 14	18	9·9	
— 12, 8.45 am.	72 13	68 23	15	8·2	
— 12, 10 am.	72 19	68 27	18	9·9	
— 12, Noon.	72 29	68 33	23	12·6	
— 13, 5 pm.	73 44	69 47	20	11	
— 13, 6.45 pm.	73 39	69 48	20	11	
— 14, 11 am.	74 25	70 5	24	13·1	
— 16, 10.30 am.	74 25	75 10	26	14·2	
— 17, 8 pm.	75 13	80 0	46	25	Clayey mud.
— 17, 12 pm.	75 10	80 31	46	25	
— 18, 0.30 am.	75 7	80 21	43	23·5	Mud.
— 18, 4 am.	74 56	79 47	46	25	
— 18, 7 am.	74 44	80 7	32	17·5	
— 18, 9 am.	74 38	80 15	26	14·2	Gray sand.
— 18, 10.30 am.	74 35	80 23	23	12·6	
— 18, 11 am.	74 32	80 27	18	9·9	Hard sand.
— 18, 11.30 am.	74 31	80 30	16	8·8	
— 18, Noon.	74 29	80 32	40	21·8	Clay.
— 18, 2 pm.	74 21	80 35	40	21·8	Clay.
— 18, 6 pm.	74 4	80 39	42	23	
— 18, 10 pm.	73 51	80 44	39	21·3	Mud.
— 18, 11 pm.	73 47	80 47	39	21·3	Mud.
— 18, Midn.	73 43	80 50	38·5	21	Mud.
— 19, 2 am.	73 43	80 54	36	19·7	
— 19, 4 am.	73 51	81 4	42	23	
— 19, 6 am.	73 50	81 11	40	22	
— 19, 7 am.	73 48	81 13	32	17·5	
— 19, 8 am.	73 44	81 15	28	15·3	
— 19, 10 am.	73 51	81 30	30	16·4	
— 19, 1 pm.	73 58	81 50	30	16·4	
— 19, 2.30 pm.	74 3	82 0	36	19·7	
— 19, 4 pm.	74 7	82 12	36	19·7	
— 19, 4.30 pm.	74 9	82 15	34	18·6	
— 19, 5.30 pm.	74 10	82 22	32	17·5	
— 19, 7 pm.	74 6	82 35	34	18·6	
— 19, 8 pm.	74 11	82 40	26	14·2	
— 19, 10 pm.	74 17	82 48	24	13·1	
— 19, 10.30 pm.	74 19	82 50	30	16·4	
— 19, Midn.	74 24	82 58	36	19·7	
— 20, 3.30 am.	74 38	83 18	86	47	
— 20, 7.30 am.	74 59	83 39	50	27·3	
— 20, 10.30 am.	75 3	84 2	50	27·3	
— 20, 1 pm.	74 57	84 40	44	24	
2 pm.	74 56	84 51	40	21·8	
3.30 pm.	74 53	85 8	20	11	
4 pm.	74 52	85 18	30	16.4	
4.30 pm.	74 51	85 24	20	11	
5.15 pm.	74 50	85 33	20	11	
5.20 pm.	74 49	85 42	26	14·2	
5.30 pm.	74 48	85 45	32	17·5	
Aug. 21, 8 am.	74 48	85 48	20	11	
— 22, 5 pm.	74 46	85 40	16	8·8	[1]
— 24, 8 pm.	75 11	85 6	50	27·3	
— 24, Midn.	75 22	84 58	47	25·7	
— 25, 4 am.	75 29	84 57	48	26·2	
— 25, 8 am.	75 24	85 13	49	26·8	
— 25, 5.30 pm.	75 24	85 48	50	27·3	Mud.
— 25, 8 pm.	75 18	86 17	47	25·7	
— 25, Midn.	75 26	86 22	50	27·3	
— 26, 4 am.	75 22	86 52	47	25·7	
— 26, 6.15 am.	75 22	87 12	40	21·8	
— 26, 8 am.	75 23	87 43	44	24	
— 26, 10 am.	75 23	88 5	40	21·8	Mud.
— 26, 10.30 am.	75 23	88 11	40	21·8	Mud.
— 26, 2 pm.	75 30	88 25	48	26·2	
— 26, 3.30 pm.	75 37	88 20	44	24	
— 26, 6 pm.	75 39	88 46	48	26·2	
— 26, 8 pm.	75 37	89 13	48	26·2	
— 26, 9 pm.	75 39	89 25	40	21·8	
— 26, 11 pm.	75 40	89 34	47	25·7	
— 26, Midn.	75 42	89 54	50	27·3	
— 27, 1 am.	75 44	90 5	52	28·5	
— 27, 2 am.	75 46	90 17	52	28·5	
— 27, 4 am.	75 51	90 42	44	24	
— 27, 6 am.	75 54	91 4	46	25·2	
— 27, 7 am.	75 56	91 13	50	27·3	
— 27, 8 am.	75 58	91 26	52	28·5	
— 27, 9 am.	76 1	91 39	52	28·5	
— 27, 9.30 am.	76 2	91 46	48	26·2	
— 27, 10 am.	76 3	91 54	44	24	
— 27, 10.30 am.	76 4	92 0	44	24	
— 27, 11 am.	76 5	92 6	42	22·9	
— 27, 11.30 am.	76 6	92 10	48	26·2	
— 27, Noon.	76 6	92 15	50	27·3	
— 27, 1 pm.	76 9	92 23	48	26·2	
— 27, 2 pm.	76 11	92 30	50	27·3	
— 27, 3.30 pm.	76 12	92 48	52	28·5	
— 27, 5.30 pm.	76 11	93 21	54	29·6	
— 27, 6.30 pm.	76 10	93 38	70	38·2	
— 27, 8 pm.	76 12	93 58	60	32·7	
— 27, 10 pm.	76 19	94 11	54	29·6	
— 27, 11 pm.	76 22	94 16	52	28 5	
— 27, Midn.	76 25	94 21	56	30·6	
— 28, 3 am.	76 31	95 2	50	27·3	Red mud.
— 28, 6 am.	76 33	94 38	48	26·2	
— 28, 7.30 am.	76 34	94 10	50	27·3	
— 28, 9 am.	76 37	94 8	44	24	
— 28, 1 pm.	76 47	94 39	22	12	
— 29, 5.30 am.	76 36	94 0	40	21·8	
— 29, 6.30 pm.	76 27	96 12	60	32·7	
Sept. 4, 6 pm.	76 12	95 42	33	18	[2]
— 7, 10 am.	76 31	98 29	15	8·2	
— 7, Noon.	76 32	98 35	13	7·1	
— 7, 0.5 pm.	76 32	98 37	12	6·6	
— 7, 0.10 pm.	76 32	98 40	10	5·5	

[1] Under the stern of the ship there was 7 m., when we anchored in 16 m. of water.
[2] In Taimur Sound.

Date and Hour.	North Lat.	East Long.	Soundings in Metres	Soundings in Engl. Fath.	Remarks.
	° ′	° ′			
Sept. 7, 0.20 pm.	76 33	98 42	11	6	
— 7, 0.30 pm.	76 33	98 45	11·5	6·3	
— 7, 0.40 pm.	76 33	98 47	12	6·6	
— 7, 9 pm.	76 31	100 48	10	5·5	
— 7, 11 pm.	76 31	100 48	11	6	
— 8, 5.30 pm.	76 32	100 48	12	6·6	
— 8, 6 pm.	76 34	100 48	10	6	
— 8, 6.30 pm.	76 34	100 48	10	6	
— 9, 9 am.	76 39	100 40	17	9·3	
— 12, 0.30 am.	76 29	113 7	13	7·1	
— 12, 1 am.	76 28	113 15	14	7·7	
— 12, 2.30 am.	76 23	113 38	20	11	
— 13, 6 am.	75 7	115 35	32	17·5	
— 13, Noon.	74 55	116 0	20	11	Mud.
— 13, 8.30 pm.	74 37	114 44	40	21·8	Mud.
— 14, 2 am.	74 27	115 0	32	17·5	
— 14, 6.30 am.	74 25	114 14	30	16·4	
— 14, 9 am.	74 18	113 43	20	11	
— 14, 10 am.	74 13	113 47	21	11·5	
— 14, 11 am.	74 8	113 53	22	12	
— 14, Noon.	74 5	113 58	25	13·7	
— 14, 1 pm.	74 2	114 3	25	13·7	
— 14, 8 pm.	73 45	114 58	13	7·1	
— 14, 8.30 pm.	73 45	115 8	11	6	
— 14, 9 pm.	73 46	115 15	10	5·5	
— 14, 10.15 pm.	73 46	115 34	10	5·5	
— 14, 10.30 pm.	73 46	115 38	8	4·4	
— 14, 10.45 pm.	73 47	115 40	7	3·8	
— 14, 11 pm.	73 47	115 45	7	3·8	
— 14, Midn.	73 48	115 35	11	6	
— 15, 0.30 am.	73 49	115 36	12	6·6	
— 15, 1.30 am.	73 51	115 40	12·5	9·6	
— 15, 2.30 am.	73 51	115 42	12	6·6	
— 15, 3.30 am.	73 48	115 42	12	6·6	
— 15, 5 am.	73 48	115 56	12	6·6	
— 15, 6 am.	73 50	116 11	16	8·8	
— 15, 7 am.	73 53	116 21	11	6	
— 15, 7.30 am.	73 55	116 23	16	8·8	
— 15, 8 am.	73 58	116 30	16	8·8	
— 15, 8 30 am.	73 57	116 31	14	7·7	
— 15, 9 am.	73 54	116 32	13	7·1	
— 15, 10 am.	73 56	116 41	12	6·6	
— 15, 10.45 am.	73 57	116 44	12	6·6	
— 15, 11 am.	73 55	116 44	13	7·1	
— 15, 11.30 am.	73 56	116 48	12	6·6	
— 15, 1 pm.	73 54	117 3	12	6·6	
— 15, 2 pm.	73 52	117 18	12	6·6	
— 15, 2.30 pm.	73 53	117 25	11	6	
— 15, 3 pm.	73 53	117 30	12	6·6	
— 15, 3.30 pm.	73 53	117 36	13	7·1	
— 15, 4 pm.	73 54	117 40	12	6·6	
— 15, 4.30 pm.	73 54	117 48	13	7·1	
— 15, 5 pm.	73 55	117 57	13	7·1	
— 15, 5.30 pm.	73 55	118 6	13	7·1	
— 15, 6.30 pm.	73 55	118 23	13	7·1	
— 15, 7 pm.	73 55	118 31	13	7·1	

Date and Hour.	North Lat.	East Long.	Soundings in Metres.	Soundings in Engl. Fath.	Remarks.
	° ′	° ′			
Sept. 15, 7.30 pm.	73 56	118 37	13	7·1	
— 15, 8 pm.	73 56	118 48	13	7·1	
— 15, 8.30 pm.	73 57	118 57	10	5·5	
— 15, 9 pm.	73 58	119 5	9	5	
— 15, 9.30 pm.	73 58	119 10	9	5	
— 15, 10.15 pm.	74 1	119 19	9	5	
— 15, 10.30 pm.	74 2	119 20	9	5	
— 15, 10.45 pm.	74 3	119 22	9	5	
— 15, 11.30 pm.	74 4	119 29	15	8·2	
— 15, Midn.	74 5	119 36	16	8·8	
— 16, 2 am.	74 7	120 6	17	9·3	
— 16, 2.30 am.	74 8	120 14	11	6	
— 16, 3 am.	74 9	120 16	11	6	
— 16, 3.30 am.	74 10	120 18	12	6·6	
— 16, 4 am.	74 12	120 20	14	7·7	
— 16, 5 am.	74 14	120 36	15	8·2	Hard bottom.
— 16, 6 am.	74 15	120 45	15	8·2	
— 16, 7 am.	74 17	120 58	15	8·2	
— 16, 8 am.	74 18	121 8	15	8·2	
— 16, 8.30 am.	74 19	121 19	15	8·2	
— 16, 9 am.	74 21	121 28	14	7·7	
— 16, 9.30 am.	74 21	121 33	14	7·7	
— 16, 10 am.	74 22	121 39	14	7·7	
— 16, 10.30 am.	74 23	121 47	14	7·7	
— 16, 11 am.	74 24	121 53	14	7·7	
— 16, 11.30 am.	74 25	122 1	14	7·7	
— 16, Noon.	74 26	122 8	14	7·7	
— 16, 0.30 pm.	74 27	122 18	14	7·7	
— 16, 1 pm.	74 28	122 26	12	6·6	
— 16, 1.30 pm.	74 30	122 34	12	6·6	
— 16, 2 pm.	74 31	122 44	12	6·6	
— 16, 3 pm.	74 33	123 1	16	8·8	
— 16, 4 pm.	74 36	123 20	19	10·4	
— 16, 5 pm.	74 37	123 34	23	12·6	
— 16, 6 pm.	74 39	123 49	30	16·4	
— 16, 10 pm.	74 47	124 53	39	21·3	
— 17, 4 am.	75 0	126 36	32	17·5	
— 17, 10 am.	74 51	128 18	$\dot{4}\overline{0}$	$\dot{2}\overline{1}\cdot\overline{8}$	
— 17, 1 pm.	74 53	128 53	$\dot{4}\overline{0}$	$\dot{2}\overline{1}\cdot\overline{8}$	
— 18, 3.30 am.	74 46	131 21	16	8·8	
— 18, 5 am.	74 45	131 50	16	8·8	
— 18, 6.30 am.	74 43	132 20	16	8·8	
— 18, 7.30 am.	74 42	132 34	16	8·8	
— 18, 9.30 am.	74 40	133 9	15	8·2	
— 18, 10.30 am.	74 39	133 25	14	7·7	
— 18, 2 pm.	74 45	134 13	16	8·8	
— 18, 11 pm.	75 22	134 51	47	25·7	
— 19, 3 am.	75 31	134 26	37	20·2	
— 19, 5 am.	75 38	134 13	37	20·2	
— 20, 6 am.	77 22	138 4	42	22·9	
— 20, 11 am.	77 47	139 1	50	27·3	
— 20, 7 pm.	77 58	136 5	80	43·7	
— 21, 9 am.	78 35	133 34	$\dot{3}\overline{0}\overline{0}$	$\dot{1}\overline{6}\overline{4}$	

2. SOUNDINGS DURING THE DRIFT IN THE ICE.

Date.	North Lat.	East Long.	Sounding in Metres.	Sounding in Engl. Fath.	Remarks.
1893.	° ′	° ′			
Sept. 21	78 40	133	$\dot{4}\dot{0}\dot{0}$	$\dot{2}\dot{1}\dot{9}$	Took several soundings the same day, but no bottom was found at 400 m.
— 23	78 45	133	$\dot{4}\dot{0}\dot{0}$	$\dot{2}\dot{1}\dot{9}$	
— 24	78 51	132 30	$\dot{4}\dot{0}\dot{0}$	$\dot{2}\dot{1}\dot{9}$	
Oct. 4	78 42	135 40	1463	800	925 fathoms of hempen line, with a lead of 50 kilogr., was let out, but the bottom was probably reached before the last 100 fathoms of line were let out. The bottom-sample consisted of a layer of gray clay, 10 or 11 cm. thick, resting on brown clay.
— 9	78 20	136 2	145	79	
— 12	78 14	135 58	90	49	
— 21	78 18·5	135 45	135	74	Bottom-sample preserved.
— 22	78 18	135 35	129	70·5	
— 23	78 17	135 30	119	65	
— 26	78 31	136 10	100	55	Gray clay.
— 27	78 28	136 0	95	52	
— 31	78 9	135 14	90	49	
Nov. 1	78 5	134 55	78	43	
— 6	77 55	136 40	55	30	
— 9	77 50	137 54	58	32	Taken at about 9 a. m.
— 9	— —	— —	53	29	Taken about noon. We had evidently moved a little from the place of the previous sounding. According to the wind, this had probably been northward; but as we had spring tide at the time, we may very well have been carried in a different direction at this time of the day.
— 21	78 24	139 18	92	50	
— 25	78 37	139 2	100	55	
— 27	78 40	138 45	140	77	
— 28	78 39	138 54	132	72	
— 30	78 41	138 40	170	93	
Dec. 3	78 45	138 20	$\dot{2}\dot{5}\dot{0}$	$\dot{1}\dot{3}\dot{7}$	
— 21	79 7·5	137 20	$\dot{1}\dot{9}\dot{2}\dot{0}$	$\dot{1}\dot{0}\dot{5}\dot{0}$	No bottom reached; had no more hempen line.
1894.					
Jan. 23	79 42	135 33	$\dot{2}\dot{4}\dot{0}$	$\dot{1}\dot{3}\dot{1}$	A walrus being seen on this date, and possibly indicating shallow sea or neighbourhood of land, the sounding was taken.
March 1	80 2	135 15	3400	1860	A sounding was tried with all our hempen line and a line of single steel wire attached, making a total length of 3475 m. A lead weighing 50 kilogr. was used. It could not be observed when the bottom was reached; but as the steel cord broke at a kink some distance above the lead, it is evident that the lead had been on the bottom, as otherwise kinks could not have formed. I assume the depth to have been about 3400 m., probably somewhat less.
April 26	80 35	131 34	$\dot{2}\dot{4}\dot{0}\dot{0}$	$\dot{1}\dot{3}\dot{1}\dot{2}$	

Date.	North Lat.	East Long.	Sounding in Metres.	Sounding in Engl. Fath.	Remarks.
1894.	° ′	° ′			
April 29	80 42·6	131 48	3800	2078	The total length of the line let out was 4000 m. It was composed of our hempen line attached to a new line of steel wire about 2000 m. in length, made of the strands of a steel cable. The lead, composed of two iron stones with a total weight of 12 kilogr., was lost, the steel line being broken at a kink some distance above the lead. Some distance higher up there was another kink, and assuming this to have been formed on the bottom, I estimate the depth to have been about 3800 m. It can hardly have been less, as otherwise many more kinks would certainly have been formed.
May 1	80 46	131 18	3800	2078	The same line as above was used, a total length of 4000 m. was let out, and the bottom was reached. A lead had been constructed so as to be released when it struck the bottom. It was composed of worn-out fire-bars from the boiler furnace. A brass tube was attached for taking a bottom-sample. The lead worked well, and the tube came up with a sample of *brownish clay*. I estimate the depth to have been about 3800 m. In my diary I estimate it to have been 3200 m.; but this is probably a mistake, for in that case many kinks would certainly have been formed.
— 26	81 30·6	123 0	2400	1312	
June 1	81 31	122 15	3450	1886	[1]
July 30	81 3·5	126 3	3300	1804	
— 31	81 3	126 10	3400	1859	
Aug. 1	81 2·5	126 33	3500	1914	
— 2	81 4	126 55	3600	1968	
— 3	81 5	127 18	3700	2023	
— 4	81 6·3	127 30	3800	2078	
— 6	81 8	127 32	4000	2187	*Bottom-sample. Brownish clay.*
— 7	81 7·6	127 27	3900	2133	*Bottom-sample. Brownish clay.* We see that the depth must consequently be between 3800 m. and 3900 m., and we may estimate it to be **3850 m. ± 50 m.** or **2105 fathoms (± 27 fathoms)**.
Oct. 22	82 1	114 45	3500	1914	*Bottom-sample.*

[1] A sounding-line of steel wire, 4450 m. long, had now been made. It was composed of first 1200 m. of two strands, then 2300 m. of three strands, and finally 900 m. of four strands. A releasing lead of fire-bars, weighing 30 kilogrammes was used. The line was let out over a meter wheel, and the following intervals noted for every 100 m.:

(*m.* means the length, in metres, of line run out, *s.* the interval in seconds used for the last 100 m.).

m.	s.	m.	s.	m.	s.	m.	s.
100	—	1100	46	2100	50	3100	50
200	45	1200	44	2200	50	3100	50
300	50	1300	50	2300	50	3300	49
400	55	1400	50	2400	50	3400	49
500	50	1500	47	2500	52	3500	53
600	45	1600	48	2600	50	3600	54
700	50	1700	50	2700	49	3700	56
800	50	1800	49	2800	50	3800	49
900	45	1900	48	2900	50	3900	48
1000	50	2000	48	3000	49	4000	51

While the line ran out the wheel was braked as evenly as possible by a man who pressed his hand, protected by a glove of canvas, against its edge. The lead probably struck the bottom between 3400 m. and 3500 m. where the interval was suddenly increased from 49 seconds to 53 seconds. The intervals increase up to 3700 m., where they again suddenly decrease, probably owing to the fact that the heavier steel line composed of 4 strands had then begun to run out. When we hauled up, the line was found to be broken at a kink at a depth of about 3200 m. As I believed that the kink had been formed on the bottom, I then assumed the depth to be 3200 m.; but I have since found by experience that kinks may be formed at some distance from the bottom, when too much line is let out.

Date.	North Lat.	East Long.	Sounding in Metres.	Sounding in Engl. Fath.	Remarks.
1894.	° ′	° ′			
Oct. 23	82 2	114 43	3200	1750	
— 24	82 3	114 41	3300	1804	
— 25	82 4	114 40	3400	1859	The steel line broke near its end. and 400 m. of hempen stray line, with the lead, was lost. The lead probably struck the bottom, and the steel line sank more rapidly than the hempen line, and thus had an opportunity to form kinks. We must consequently assume the depth to have been about **3350 m.** (± **50 m.**) or **1832 fathoms** (± **27 fath.**).
— 29	82 10	113 30	3000	1640	
Dec. 19	82 50.5	104 45	3000	1640	
— 20	82 52	104 25	3200	1750	
— 21	82 54	104 4	3400?	1859?	The hempen stray line broke, and the lead was lost.
— 27	83 22	102 27?	3400	1859	As the steel line was not longer than 3400 m., more steel line had to be made.
1895.					
Jan. 23	83 23·5	102 14	3600	1968	*Bottom-sample. Brownish clay.*
— 23	— —	— —	3500	1914	*Bottom-sample. Brownish clay.* As the position was very nearly the same on Dec. 27, 1894, we may assume the depth to be **3450 m.** (± **50 m.**) or **1886 fathoms** (± **27 fath.**).
April 25	84 13	94 10	3000	1640	
— 25	— —	— —	3200	1750	
— 25	— —	— —	3400?	1859?	The line broke during the hauling up, and 500 m. of steel wire was lost.
July 22	84 36·3	72 40	2500	1367	
— 22	— —	— —	3000	1640	
— 23	84 34	72 20	3400	1859	
— 23	— —	— —	3800	2078	Bottom-sample.
— 24	84 32	71 50	3600	1968	The depth may consequently be assumed to have been **3700 m.** ± **100 m.** or **1023 fathoms** ± **55 fath.**
Nov. 29	85 28	59 0	3000	1640	
1896.					
Jan. 23	84 58	37 20	3000	1640	
April 15	84 7	16 0	3000	1640	
July 6	82 59	12 48	3000	1640	
— 8	83 2	12 52	3400	1859	Bottom was reached, and the depth was consequently **3200 m.** ± **200 m.** or **1750 fathoms** ± **109 fath.**

III. THE CONTINENTAL SHELVES AND SUBMERGED VALLEYS OF THE NORTH POLAR SEA.

The general idea prevailing before our expedition, was that the North Polar Ocean, between Siberia and North America, was a shallow sea, with a comparatively rapid deposition of sediments carried into it by the Siberian and American rivers, and also brought from the coasts by the drifting ice. The idea probably shared by many geographers was that this enclosed sea, even if it had once been deeper, had gradually in the course of time been filled up by this process;[1] and moreover, it was generally expected that unknown lands would be found in the north. Several geographers, for instance, even considered what was then known of Franz Josef Land to be the southern coast of an extensive continent, with inland-ice forming large icebergs. Greenland was also supposed to extend far northward, and as the Jeanette Expedition had discovered new islands (De Long Islands and Bennett Land) near its farthest north, and Baron v. Toll had seen Sannikov Land to the north of Kotelnoi, it was not unnatural to expect that more land existed still farther north.

Our expedition has proved that these conceptions were incorrect in several important respects. On the one hand we found a deep sea in the north, forming a basin with depths approaching 4000 metres; on the other hand, the bottom-samples from this deep basin seem to indicate that, at present at any rate, there is no very rapid deposition of sediments on the bottom of the deep basin. Thirdly, our expedition proved conclusively that Franz Josef Land was a group of comparatively small islands, which did not extend

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[1] Cf. A. Supan, Grundzüge der Physischen Erdkunde, Leipzig, 1896, p. 199.

very far towards the north; and our observations also revealed the probability that no extensive land-masses existed to the north of the New Siberian Islands[1]. In short, our expedition has proved the unknown polar area to be an enclosed deep basin, where no great land-masses can be expected to exist. This deep basin is probably separated from the deeps of the Norwegian Sea by a comporatively shallow sub-oceanic ridge extending from Spitsbergen to Greenland.

The bathymetrical features of the North Polar Basin are in several respects interesting, and are different from those of most other enclosed seas. On the chart, Pl. I, I have made an attempt to represent the bathymetrical features of the Northern Seas, as they might be according to our soundings and those known from other expeditions. The isobaths drawn in the North Polar Basin are of course very hypothetical, as the soundings are too few and too far between to allow of anything else. But although the isobaths may be very far from correct in many places, they may still give a general idea of the configuration of the sea-bottom in this region.

A. THE SIBERIAN CONTINENTAL SHELF.

The most striking bathymetrical feature of the North Polar Seas seems to me to be the exceptionally broad and shallow continental shelf which extends northwards from the Eurasian continent. The Arctic islands, Bear Island, the Spitsbergen Archipelago, the Franz Josef Archipelago, Novaya Zemlya, Ensomheden (Lonely Island), the New Siberian Islands, Bennett Land, De Long Islands, Wrangel Island, and Herald Island, are all situated on this immense submarine platform, above which the depths do not, as a rule, exceed 200 m., and are generally less than 100 m. The American Arctic continental shelf with the Arctic Archipelago may be considered as a direct continuation of the Siberian platform. Davis Strait with the deep Baffin Bay, and the Norwegian Sea with the deep depression of the North Polar Basin, form, as it were, with their many branches (*e. g.* the Barents Sea), enormous fjords penetrating into this extensive submarine platform. The deep depressions of these oceanic fjords are, however, shut off from the Atlantic abyss by several transverse ridges, in a manner altogether similar to that in which the

[1] Robert Peary has now also proved that Greenland does not extend very far towards the north. He found the northern termination of its land-mass to be situated in 83° 39′ N. Lat. 33° 20′ W. Long.

great depths of the Norwegian fjords are shut off, often by several thresholds, from the oceanic abyss outside. As examples may be mentioned the sub-oceanic ridge across Davis Strait from Greenland to Baffin Land, the Iceland-Greenland Ridge across Denmark Strait, the Shetland-Færoe-Iceland Ridge, and the probable sub-oceanic ridge from Spitsbergen to Greenland (cf. vol. III, No. 9, p. 407).

The total area of the North Polar Continental Shelf cannot be determined at present, as we know only in a few places the situation of its northern margin, but it appears to be the most extensive, continuous continental shelf on the Earth's surface. It would be of much interest in several respects to know the surface-configuration of this extensive platform as it might greatly aid in solving the problem of the true origin of this and similar formations; but the supply of observations to work upon is unfortunately still very meagre in this respect.

Our soundings along the Siberian coast from Yalmal to the New Siberian Islands seem to prove that on the whole the sea off this coast is comparatively very shallow (most depths are between 7 m. and 50 m.), and the depths are, as a rule, quite remarkably uniform for great distances. The soundings made during the *Vega* Expedition give the same evidence. It often made no great difference in this respect whether we were off a typical low coast, *e. g.* Yalmal or the coast between the mouths of the Anabara and the Olenek, or off a steeper coast with fjords and islands, *e. g.* the coast between the mouths of the Yenisei and the Taimur Rivers, except that it was as a rule somewhat deeper (about 20 or 30 m. deeper) off the latter coast. The greatest depths observed near the coast were those found during the Vega Expedition north of the most northerly projection, the Chelyuskin Peninsula where we probably have the nearest approach to the northern edge of the continental shelf, and where the land within is comparatively high. In about 77° 39′ N. Lat., 105° 7′ E. Long., 124 m. was found only a few miles from the coast a little farther east 87 m. is recorded near the coast on NORDENSKIÖLD's chart, and in 77° 24′ N. Lat., 108° 20′ E. Long. 89 m.[1]

[1] There are several discrepancies between the soundings recorded on NORDENSKIÖLD's chart (*Vega-Expeditionens Vetensk. Iakttagelser*, vol. I, Pl. 1) and those given for the same places by O. PETTERSSON. In the first of the places mentioned above, PETTERSSON gives 128 m. instead of 124 m. and in the last-named place 100 m. where NORDENSKIÖLD has 89 m.; and in PETTERSSON's Section V (Pl. 24), it looks as if no bottom was found at 100 m. (*Vega Exp. vet. Iaktt.*, vol. II, pp. 357, 365, and Pl. 24.)

The soundings during the Fram's voyage northward from the sea north of the Lena Delta, also show a remarkable uniformity of depth, with a slow increase northward from 14 m., in 74° 39′ N. Lat., 133° 25′ E. Long., to 80 m. in 77° 58′ N. Lat., 136° 5′ E. Long., north of which place, at a distance of about 550 kilometres from the Siberian coast, the bottom suddenly descends abruptly towards the abysmal floor of the basin.

The many soundings taken during the drift of the *Jeanette*, from September, 1879, to June, 1881[1], show that the floor of the submarine platform between Herald Island (north of Bering Strait) and De Long Islands is on the whole remarkably level, even at such great distances as these from the Siberian coast. During the first part of the drift, when the ship was in the waters north-east of Bering Strait and near Wrangel and Herald Islands, most depths varied quite gradually between 32 m. and 73 m. The distance from the Siberian coast was then generally about 340 kilometres. Farther towards the north-west, in an area bounded by latitude 73° and 74° N. and longitudes 176° and 179° E., the depths would vary between 43 m. and 80 m. The mean distance of this area from the Siberian coast is 430 kilometres. Beyond this area the depth increased more or less gradually from 58 m. in 74° 8′ N. Lat., 175° 32′ E. Long. to about 100 m., and then more rapidly to 156 m. in about 75° 50′ N. Lat., 169° 56′ E. Long. The distance of the latter place from the Siberian coast was about 640 kilometres. During this part of the drift, it seemed as if the depth increased comparatively rapidly as soon as the ship deviated from the general direction of her drift towards the north-east; she was probably near the margin of the platform, and travelled for some distance very nearly along it. The soundings seem to indicate that the edge of the general floor of the shelf was situated at about 100 m. below the sea surface. From the deepest place just mentioned, the depths again decreased towards the sea near De Long Islands, where they varied between 60 m. and 79 m.

The soundings of the various expeditions in the sea to the north of Bering Strait show that there also the depths are on the whole very uniform, increasing gradually from 50 m. near Bering Strait to about 100 m. and then more rapidly to 150 m. in about 73° 50′ N. Lat., 172° W. Long., at a distance

[1] The Voyage of the Jeanette. The Ship and Ice Journals of George W. De Long. Edited by Emma De Long. Vols. I and II, London, 1883.

of about 600 kilometres from the Siberian coast. Only at the Herald Shoal, in 70° 22′ N. Lat., 171° 10′ E. Long., do the depths decrease to 13 m. below sea-level.

In the region of the Franz Josef Archipelago, the depths seem to be more irregular. Near the western extremity of these islands the Jackson-Harmsworth Expedition found a depth of 512 m.[1], and depths greater than 300 m. do not seem to be uncommon along the shores of these islands. Near their eastern coast Admiral MAKAROFF found no bottom at 200 m. and 350 m. The platform of the Franz Josef Archipelago is evidently dissected by deep submarine valleys, probably communicating with the North Polar Basin. It seems to be separated from the Siberian continental shelf by a deep embayment extending from the North Polar Basin southward towards Novaya Zemlya (see Pl. I).[2]

On the whole, it is evident from what we know of the continental shelf to the north of Siberia, that it is remarkably level and shallow. How can we explain the fact of such an extensive platform having become so extremely level? Can its levelness be considered as an indication that it has not, within comparatively recent times, been elevated into dry land, as most other known continental shelves have evidently been? This can hardly be answered in the affirmative. The western Taimur coast is evidently to a very great extent a typical fjord-coast, which must have been formed by the submergence of an uneven land-surface with valleys and river channels. As the present land is nowhere very high, we cannot suppose the valleys to have been very

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[1] F. G. JACKSON, A Thousand Days in the Arctic, London, 1899, map No. 4, opposite p. 640. According to kind communication from Mr. WILLIAM S. BRUCE, the sounding of 280 fathoms (512 m.) is not correctly situated in Mr. JACKSON's map, the sounding having been taken near Cape MARY HARMSWORTH.

[2] During the Tegetthoff Expedition 515 m. was sounded in this embayment. In my Memoir, vol. III, No. 9, p. 289, I have assumed for oceanographical reasons that a submarine ridge, separating the Kara Sea Basin from the North Polar Basin, unites the Franz Josef Archipelago with the western Taimur Peninsula and the Nordenskiöld Islands. In August, 1901, Admiral MAKAROFF, on board the Ermak, took several series of deep-sea temperatures and water samples in the sea between Novaya Zemlya and the Franz Josef Archipelago and east of the latter, and these he had the great kindness to send me for examination. The resemblance between the salinities of these water samples, as well as the temperatures, and those found at similar depths in the North Polar Basin makes it, in my opinion, probable that there is an open communication between the two basins, and that they are separated from the Kara Sea basin (near the east coast of Novaya Zemlya) and the Barents Sea by submarine ridges extending from the northern part of Novaya Zemlya towards the ptatform north of Yalmal, and towards Spitsbergen (see Pl. I).

deep with steep side slopes; but we may nevertheless assume with certainty that the submerged land-surface now forming the bottom of the sea off the Siberian coast, especially off the western Taimur coast, was originally sculptured with depressions and furrows, these being submarine continuations of the sounds, fjords, and valleys on the coast and the land within.[1] These depressions may to some extent have been filled up by ground moraines during the glacial epoch, and also by the deposition of glacial sediments outside the margin of the Siberian ice-sheet;[2] but the present remarkable uniformity in the depths, at any rate near the coasts, may also to some smaller extent be due to a comparatively recent silting up by deposits from the rivers and the shores. The floating ice will also help to make the bottom of the shallow sea very level, as the drifting hummocks, with their bases reaching down to perhaps 30 or 40 m., and sometimes much deeper, will be grounded on all saliences on the bottom with smaller depths; and being then exposed to the ice-pressure, these hummocks will have an extraordinary power of planing down all unevennesses, especially if they consist of soft deposits, and will carry the loose matter into all depressions. All ice-pressures in the direction of the shore, *e. g.* during heavy gales, will also form hundreds of grounded hummocks which will be pushed like planes towards the shore with irresistible force; and it is clear that this circumstance will greatly tend to make the bottom of the shallow sea off the coast unusually level and smooth, especially if the bottom be covered with soft deposits (sand or clay) or gravel, which will easily yield to the pressure of the ice. Thus we find an explanation of the circumstance that both the Vega and the Fram could often sail long distances along the coasts of eastern Siberia, east of the Taimur Peninsula, (*e. g.* outside the Anabara and the Lena, etc.) with only some few metres of water under their keel, without running the risk of being suddenly grounded; for the hummocks had levelled the way for them.

It does not seem improbable that in the shallow sea near the Siberian coast, the deposition of sediments is comparatively rapid, for on the one hand

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[1] We do not know at present whether the fjords of the Taimur coast are generally deeper than the sea outside, like the Norwegian fjords, although this may seem probable. In Taimur Sound we did not happen to find greater depths than in the sea outside.

[2] That this has actually to some extent been the case, is indicated by the soundings of the Jeanette Expedition, as gravel (and pebbles) are several times recorded at great distances from land.

much waste is naturally carried into this sea by the Siberian rivers, and much is evidently also formed by the marine denudation of the coasts (cf. the retreating coasts of the Liakov and New Siberian Islands where the mammoth-hunters find the tusks); and on the other hand the forces which in many other regions of the Ocean counteract the formation of deposits in the shallow water of the continental shelves are not so active in this enclosed, ice-covered sea. The formation of waves is greatly impeded by the floating ice which almost entirely covers the sea during the greater part of the year. The permanent sea-currents are very slow in this enclosed sea, and the tidal currents are also comparatively unimportant.[1] It seems therefore quite natural that, at least near land, the surface of the Siberian continental shelf should be very level and at no great depth, and we cannot expect, as a rule, to find many traces of the river-valleys which may originally have existed, especially in its shallower parts. If such traces still exist, we might expect to find them especially in the northern parts of the platform near its margin. Our soundings taken north of the New Siberian Islands on October 9th, 12th, 26th, and 27th, 1893, were situated in a straight line, very nearly along the meridian of 136° E. Long. between 78° 14′ and 78° 31′ N. Lat. Farthest north (Oct. 26) the depth was 100 m.,[2] three miles farther south it was 95 m., eight miles farther south (Oct. 9) it was 145 m., and six miles still farther south it was 90 m. There was consequently here a comparatively narrow depression of 50 m. below the general floor of the platform, which might very well have been part of a submerged river-valley.[3] The Jeanette soundings also indicate that in a few places there were slight and apparently irregular depressions in the general floor of

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[1] At the same time it might, however, be mentioned that our bottom-samples from the shallow Siberian Sea vary comparatively much, even at great distances from land (cf. BØGGILD's Memoir, No. 14). The soundings taken during the Jeanette Expedition (cf. l. c.) also seem to indicate great variety in the bottom, as sometimes sand, sometimes clay or mud, sometimes gravel is recorded, often within limited areas and at great distances from land. This seems to indicate that the general floor of the continental shelf cannot have been covered by any very thick layer of deposit since it was last elevated above sea-level; for this deposit would naturally be expected to be rather uniform in its composition, over extensive areas.

[2] This was very near the edge of the continental shelf, where it breaks off along an abrupt descent towards the North Polar abyss. Only 14 miles farther towards the north-east, the depth was 1460 m.

[3] The different nature of the two samples, Nos. *8a* and *8b*, from this region (see BØGGILD, next Memoir), might also indicate that there are differences, not dating from most recent times, since the present sea-level was established.

the platform. On April 26th, 1880, when in 72° 56′ N. Lat., 179° 16′ W. Long., De Long states that the soundings suddenly decreased to 57 m. (31 fathoms), while on the previous day, only 2·5 miles to the south-east the depth was 81 m. (44·5 fathoms), and two days before, on April 24th, in 72° 52′ N. Lat., 68 m. Farther to the south-east, the depths were between 56 m. and 60 m. There was consequently a depression of 24 m. below the general floor of the platform, and this seems to be exceptionally great for this level submarine plain. De Long remarks[1]: "We must assume that we struck a deep hole". It seems possible that this hole was actually part of a submerged valley, which was crossed. On August 9th, 1880, in 73° 25′ N. Lat., 176° 39′ W. Long., De Long records 71 m. (39 fathoms), on August 15th 72 m., and on August 18th 80 m. (44 fathoms) "with mud, gravel, and fine white sand". Unfortunately no localities are given for the last two soundings, but it seems as if not far off in the same region there were depths of 43 and 44 m. (on June 19th and 26th, 1880). On August 29th, 1880, in 73° 41′ N. Lat., 177° 13′ E. Long., 68 m. was sounded, while on June 16th, 1880, very nearly on the same spot (in 73° 41′ N. Lat., 177° 18′ E. Long.) a depth of 46 m. was found, and in other places in the neigbourhood soundings of between 43 and 49 m. were taken. It thus appears as if there were depressions of 20 or 30 m. in the platform in this region, where its general floor was situated at about 40 or 50 m.; and it is very possible that these depressions, in which were found "mud, gravel, and fine white sand", were actually submerged river-valleys. In the region where the Jeanette was evidently near the margin of the platform, and where depths of from 148 to 156 m. were observed, there were, however, no indications of submerged valleys; the depths seemed to decrease very regularly both south and north-west of this region.

I have already mentioned that near the coasts of the Franz Josef Archipelago, the soundings give less regular depths; and it seems probable that good specimens of typical submerged valleys may be found in this region, where we also have much greater heights on the land within, and comparatively deep fjords and sounds with steep sides.

The slope of the Siberian continental platform seems to be unusually level. Along the Fram's track, from 74° 39′ N. Lat., 133° 25′ E. Long., where

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[1] L. c., p. 331.

the depth was 14 m., to the edge of the continental shelf in about 78° 14′ N. Lat., with a depth of about 100 m., the distance was about 400 kilometres. The slope was consequently about 1 in 4650, or the angle of descent was only 44″. The slope measured from the Siberian coast to the same place was about 1 in 5500, or 38″, and from the northern termination of Kotelnoi to the margin of the platform, it was about 1 in 2480, or an angle of about 1′ 23″. The slope from the Siberian coast to the Jeanette's deepest (156 m., see p. 15) was about 1 in 4100, or 50″; but as this sounding was probably made beyond the actual edge of the shelf, it might be more correct to measure the slope to some sounding made at a spot situated a little nearer the coast, when we should get considerably smaller angles. If compared with the slope of the continental shelf in other regions, *e. g.* off the European coast, these angles are very small; while the angle of the continental slope from the edge of the continental shelf seems to be comparatively great. According to our soundings in October, 1893, it was about 1 in 17·7, or about 3° 15′, which is very nearly the same as the steepest slope at Storeggen off the Norwegian west coast.

The *edge* of the platform seems to be very sharply defined, at any rate to the north and north-west of Kotelnoi, where its *depth*, in three different places passed by the Fram, seems to be very nearly 100 m. This is a comparatively small depth; the depth of the edge off the European coast is in most places greater (see later). As already mentioned (p. 15), the edge of the continental shelf seems to be situated at very nearly the same depth of 100 m. farther east along the route of the Jeanette (in about 170° E. Long.), and also to the north of Bering Strait (cf. p. 15).

North of Spitsbergen and the Northeast Land, the edge of the platform has evidently a deeper situation, although the soundings are too few to give any definite information in this respect.

The Siberian Coast Platform. In connection with this description of the Siberian continental shelf I ought perhaps to mention the present coast line, and a formation which possibly is similar to the Norwegian coast platform or "Strandfladen" (see later). Along the whole western coast of the Chelyuskin Peninsula I observed a very flat low land extending in front of the mountains within, which ascended comparatively abruptly from the low

plain (see Pl. III). In the sea far outside the coast I also observed several low islands (the Thomas Fearnley Islands and the Axel Heiberg Islands). Along the northern and norwestern coast of the eastern Taimur Peninsula, east of the Chelyuskin Peninsula, I observed a similar low land in front of the comparatively high mountains within (see Pl. III). This low land, is evidently a very characteristic feature of great parts of the northern Siberian coasts. Seen in a distance it seemed to form an extremely level plain especially along the Chelyuskin Peninsula and east of it, with a very uniform height above present sea-level, and generally with a steep, abrupt descent forming the present shore. Unfortunately I had no opportunity of measuring its height above sea-level, but would estimate it to be less than 20 m. or 30 m. Seen from the sea it made at many places the impression of being a coastal terrace built up of coast sediments, and perhaps glacial drift, but in some places along the west coast of the Chelyuskin Peninsula, where we were the coast sufficiently near, I believed with certainty to see rocks *in situ* near the shore, and there this coast platform was evidently to a great extent cut in solid rocks. At the north-eastern corner of the Chelyuskin Peninsula we landed on a low island, with a flat level surface, evidently being part of the same low land. The surface of this island consisted of hard quartzite covered by a thin earthy layer with rocky debris. Farther south at the head of Toll Bay I was also ashore. There was a quite similar low land, the general floor of which ascended gently inland, in some few places surmounted by comparatively low hills. On this plain I found nowhere rocks *in situ*. It was built up chiefly of soft deposits of sandy clay, in which boulders, were imbedded, and the surface was strewn with great blocks and boulders, with comparatively sharp edges. The surface of the plain did not seem, however, to be quite so level as farther north, it was on the whole perhaps somewhat higher and more rolling, at least at some distance from the coast, and had quite recently been dissected by streams and rivulets now forming furrows with steep side slopes in the earthy layers. It made the impression of having once stood at a lower level, when its slightly rolling surface was formed, and had comparatively recently been elevated to its present level.

It may be difficult to decide at present whether the coast platform, or coast terrace, is simply a part of the continental shelf which has now been partly

elevated above sea-level. It would then form, what the American geologists would call a coastal plain, perhaps like great parts of the northern Siberian low land. To me it seems, however, probable that it is a somewhat different formation, analogous to the Norwegian coast platform ("Strandfladen", see later). It evidently marks a definite previous sea-level, and doubtless is, at some places at least, carved in solid rocks (gneiss, micashists, granites, quartzite) *in situ*, evidently by marine denudation. I consider it very probable that the great number of low, and generally rocky islands, which we found, often far from land, along the northwestern Taimur coast, from the mouth of the Yenisei to the Nordenskiöld Islands, were parts of the same coast platform. Most of these islands seemed to have much the same low heights which very seldom rose to much above 20 m. or 30 m. above sea-level, generally much less, often only a few metres, while on the land within higher hills were often sighted.

The land surrounding Yugor Strait, both on the southern side and on Vaigach, is also very low, and comparatively flat, forming a gently rolling low plain, but with no higher hills in the neighbourhood. Along the coasts of the strait, *e. g.* on the northern side of its western entrance, the layers of the exposed rock seemed to have been much folded, but the folds were all cut at a certain level by the present plain, which seemed to have formed originally a plane of denudation, and I should say chiefly marine denudation. At two places on the continental side of the strait where I had an opportunity to examine the rocks, they consisted of more or less soft Silurian shists[1] which would easily yield to the attacks of marine denudation.

It is therefore, according to my view, probable that a coast platform, carved in solid rock similarly to the Norwegian coast platform, has to some extent been formed along the Siberian coast, but at many places coast terraces have been formed at about the same level by sediments or glacial drift. It may in this connection be of some interest that the Yalmal Peninsula, at least on its west coast where I was on land, formed a similarly low, gently rolling plain, at much the same level, and as far as I saw, greatly built up of glacial drift.

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[1] Cf. J. KIÆR, in vol. IV, No. 12, of the present Report.

B. THE AMERICAN ARCTIC CONTINENTAL SHELF.

On the American side of the North Polar Basin, the continental shelf seems to have a smaller extent and to be less regularly developed than on the Siberian side. North of Alaska the margin of the continental shelf approaches to within 70 kilometres of the coast north of Point Barrow. In August, 1850, Capt. COLLINSON sounded 115 m. about 66 kilometres (36 miles) due north from Point Barrow; while about 100 kilometres to the north-east of the same cape, he sounded 252 m., and a short distance farther east (at about the same distance from land) he found no bottom at 265 m. Farther east, in 70° 30′ N. Lat., 139° 45′ W. Long., no bottom was found at 347 m. about 100 kilometres north from the coast, while 91 m. was sounded about 20 kilometres farther south. A little farther east, in 70° 16′ N. Lat., 138° 50′ W. Long., no bottom was found at 265 m., about 65 kilometres (35 miles) north of Herschel Island. A submarine valley seems to approach this island, as depths of 148 m. and 163 m. were found until quite near the coast, where the general floor of the continental shelf seems to be at a depth of between 36 m. and 55 m. The edge of the continental shelf is evidently situated at a depth of about 100 m., or very nearly the same as found by us north of the New Siberian Islands. In the sound between Baring Land and the continent, a sounding of 294 m. was taken quite near the coast (in Franklin Bay); and many soundings gave no bottom at 200 m. or 250 m. Farther east in the narrow sound between Victoria Land and the continent, depths of 229 m. and 277 m. were found, and several soundings giving no bottom at 205 m. are recorded. In the sounds between the islands of the Arctic Archipelago, comparatively great depths are found in many places, wherever soundings have been taken. In Mc. Clure Strait for instance, near Cape Providence (Dundas Peninsula) on Melville Island, a depth of 411 m. was found; in Lancaster Sound 512 m. was sounded; and farther north in Cardigan Strait (between North Devon and North Kent), in 76° 44′ N. Lat., 91° 10′ W. Long., no bottom was found at 732 m. (400 fathoms). The whole region of the Arctic Archipelago is evidently a typical fjord region, with deep submarine channels where still greater depths may be expected to exist, and it seems probable that these channels extend northward, traversing the possible continental shelf, and originally opening out into the abysmal region of the North Polar Basin. It seems to me probable that the depths of these channels or sub-

marine fjords may be more or less reduced on the continental shelf north of the islands, as is the case along the Norwegian coast (see later). It is thus hardly probable that the continental shelf is of any great extent in this direction, and it has certainly no level, shallow floor similar to that of the Siberian shelf.

North of Grant Land (or Grinnell Land) and Greenland, the continental shelf seems, at any rate, to be of some considerable extent; for Markham, at his farthest, about 50 kilometres from land, sounded 132 m.

C. THE KARA SEA.

The bathymetrical features of the Kara Sea between Novaya Zemlya and Yalmal and farther north (see Pl. II), seem to be rather different from those of the Siberian Sea. West and north of Yalmal there is evidently a distinct continental shelf, which on the whole has very uniform, shallow depths especially near the coasts. But towards the edge of this shelf there are many depressions, which seem to have the typical character of submerged valleys. In some places they even approach the coast. Towards the north-west and north from Beli Ostrov (White Island), the continental shelf seems to be most distinctly developed. Measured north from this island, it is about 200 kilometres broad, and unusually shallow, the depths being between 20 and 40 m. The slope is thus no more than 1 in 4850, or about 42″. But at the edge, in about 40 m., it breaks off along a comparatively steep descent towards the bottom of the channel east of Novaya Zemlya, forming at some places a slope of perhaps 1 in 50, or 1° 46′. The valley-like incisions in this extraordinarily level platform are often comparatively narrow and deep. In about 73° 40′ N. Lat., 67° E. Long. there is a channel, which, at a width of perhaps 20 kilometres, forms a depression of 135 m. below the general floor of the platform. In about 74° 50′ N. Lat., 70° E. Long., there is an incision forming a depression of 120 m. in the platform; and in about 72° N. Lat., 66° E. Long. there is a distinct channel with a similar depression, and with a tributary approaching the coast. In about 70° 35′ N. Lat. a submarine valley seems also to approach the coast. These channels cannot easily, according to my view, be explained in any other way than as submerged valleys originally formed by atmospheric erosion on a dry land-surface. A

similar sculpturing of the sea-bottom cannot have been formed at the present sea-level. The possibility of submarine excavation of valleys by local glaciers seems to be excluded in such a flat region with uniform heights. The existence of these submerged valleys in the edge of the continental shelf is an important evidence that, although there may be a comparatively rapid formation of deposit on the bottom of this sea, so near the mouths of the Obi and the Yenisei, this has not been sufficient to obliterate the sculpturing of the previous land-surface.

The isolated deep depressions with depths of 560 m. and even 743 m., west of Vaigach and Yugor Strait cannot possibly be ascribed to ordinary erosion of a land-surface, but have probably been formed by dislocations or faults, although the possibility that they may have been formed by local excavation of glaciers is not excluded, especially if the ground consist of weak sediments or earthy layers. But in this case local glaciers would hardly be able to excavate depths of 743 m., unless the ground were elevated more than it is at present.

It seems probable that the deeper channel along the east coast of Novaya Zemlya has originally been formed by dislocations; it has the typical curved shape of a sunken area, but nevertheless its present sculpturing seems, to some extent at least, to be due to subsequent atmospheric erosion, and it does not seem improbable that it has formed the bed of a river, and perhaps also of a glacier, originally draining into the North Polar Basin east of the Franz Josef Archipelago. In 74° N. Lat., a shallower ridge seems to cross the channel, and it might seem natural to suppose that this was due to the deposition of matter carried thither, partly on shore ice, by the waters of the Obi which to some extent pass in this direction; but such an explanation can hardly be accepted, seeing that a comparatively deep valley passes towards the north-east, east of this ridge, and if the above supposition were correct, this valley would naturally also have been filled up. If such a ridge actually exists, it ought more probably to be ascribed to the deposition of moraine matter during the glacial periods. The possibility that other ridges may cross the channel farther north is not excluded.

IV. THE BATHYMETRICAL FEATURES OF THE BARENTS AND MURMAN SEA.

On the chart, Pl. II, I have introduced the soundings taken in the Barents Murman, and Kara Seas, by the many recent expeditions[1], and have drawn the isobaths for every 50 m. In several places additional soundings would be highly desirable, in order to enable us to trace out the contours with more detail. But the depths known seem nevertheless sufficient to show us that the physical features of the bottom of this sea bear a striking resemblance to those of a formerly subaërial region, and may claim special interest. We have here an extensive coherent system of broad and narrow submarine valleys which appear once to have formed the bed of a great river, with its many tributaries, draining an extensive area of the ancient continent as far east as Novaya Zemlya. The whole bottom of this extensive and comparatively

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[1] The chief sources used for our chart are the most recent revised Russian Charts, the English Admiralty Charts (soundings which were doubtful have been left out), and the charts of the Norwegian Hydrographic Survey (Den Norske Geografiske Opmaaling). I have also introduced soundings taken during the six voyages with the 'Willem Barents', 1878—1883; the Norwegian North Atlantic Expedition, 1878, the Vega Expedition, 1878, the Fram Expedition, 1893, the voyage of William S. Bruce on board the Blencathra, 1898, the latest voyages of Dr. Knipowich, 1899, 1900, (Dr. Knipowich has also had the great kindness to send me his soundings from the summer of 1901), the voyage with the Heimdal of the Norwegian Navy, 1900, and the voyage of Capt. Roald Amundsen in the Gjøa, 1901.

Den Norske Geografiske Opmaaling has also shown me the great kindness to let me have their soundings off the Finmarken coast from 1901, which have not yet been published. In this region the soundings were too numerous to be introduced on the chart.

As Mr. Bruce's soundings from 1898 were introduced on the chart after the isobaths and colours had already been printed, the contours at some few places are incorrect.

shallow sea, seems consequently to have been elevated above sea-level at some previous and probably not very remote geological period. No other theory would, in my opinion, serve to explain the origin and presence of such a system of valleys under the water of the sea. Depressions may certainly be formed by dislocations, and even valleys may be formed by faults or folding, owing to seismic strain and tangential pressure; and in fact we know that suboceanic changes such as these do constantly occur[1]. But we cannot expect the depressions thus formed, to assume, without the aid of meteoric agencies, the shape of typical river valleys, with numerous branches, or tributaries, all converging into a trunk valley, which on the whole gradually deepens towards its embouchure, opening out into the oceanic abyss[2].

Let us, for a moment, assume that there has been formed in this region by seismic strain a succession of ridges with longitudinal depressions in between. Novaya Zemlya may be such a mountain ridge, with depressions on each side, namely, the channel of the Kara Sea, and the submarine channel on its west side along the meridians of 40° and 44° E. (Pl. II). From the western Murman Coast a second ridge may have extended towards Lat. 77° N. and Long. 40° E. (Pl. II), and a third ridge from Finmarken towards the plateau of Bear Island and Hope Island. But these ridges must nevertheless have been dissected by erosion of some kind, for the branch valleys passing transversely to the direction of the mountain ridges cannot all have been formed by seismic strain of some kind. And moreover, a narrow channel, for instance like that passing along the coast of East Finmarken (Pl. II), — let us call it the Vardø Submarine Channel — and receiving tributaries from different directions, one from the Varanger Fjord, another from the south-east, etc., exhibits the typical features of a former river channel and afterwards glacial valley, and

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[1] Cf. MILNE, 'Sub-Oceanic Changes', *Geographical Journal*, vol. X, 1897.

[2] I consider it probable that depressions, or geological dislocations of some kind, generally due to folding or faults, formed as a rule the original base of the channels or valleys of water erosion or glacial erosion. It may be, for instance, that the sinking in along a line of fault has brought softer sedimentary rocks down on to a level with harder archæan rocks; and as the softer rocks were more easily eroded, the main direction of the river-valley (and later glacial valley) came quite naturally to follow, more or less, the direction of the original line of fault. Prof. BRØGGER has pointed out that this has been the case during the formation of the Christiania Fjord and the Langesund Fjord (Nyt Mag. for Naturvidenskaberne, vol. XXVIII, 1884, vol. XXX, 1886); and many other fjords will certainly also be found to have been formed in a similar manner or by folding (*e. g.* the Trondhjem Fjord, cf. what is said later of the longitudinal valleys and fjords of Northern Norway).

can hardly be explained otherwise than as having been formed by erosion of a former land surface elevated to a height of at least 450 m. above sea level, and probably much higher.

The possibility exists that there has been no oscillation of sea level, but that the channels may have been excavated by glaciers to their present position below the sea surface. But this possibility is not of much weight, as far as I can see. If, for instance, the Vardø Submarine Channel did not to some extent exist before the submarine glacial erosion commenced, how could the excavation by an ice-sheet be sufficiently limited on such a level surface to carve this crooked, narrow channel with its tributaries far out to sea, where the weight of the ice over the bottom of the channel would moreover be reduced by its buoyancy in 400 m. of sea-water? To explain in this manner the formation of narrow channels on the comparatively level sea bottom even much farther from land (see Pl. II), would lead to still greater difficulties. It seems much simpler to assume that the bottom was formerly elevated, and that the valleys were carved originally by streams, and later by glaciers, on a land surface. The fact that the deepest hollows of the submarine channels are often separated by barriers from the depths of the ocean outside (*e. g.* the Vardø Channel), will form no disproof of a theory such as this; it is a universal feature of submarine channels of formerly glaciated countries, and I consider it probable that the barriers of this region were formed to a great extent by glacial drift, etc., after the valleys.

It might be objected that the submerged valleys of the Barents Murman Sea are on the whole too broad, and have side slopes too gentle, to resemble ordinary river valleys. But on the one hand it should be distinctly remembered that the soundings are not, as a rule, nearly numerous enough to enable us to trace out the features of most valleys with the needful minuteness of detail, though where this is possible, *e. g.* near the Finmarken coast, the character of river channels and glacial valleys is very conspicuous; and on the other hand, to whatever height the sea bottom may have been elevated, it has formed a comparatively flat region, where the river valleys have naturally become broad and relatively shallow, as on the Russian and Siberian plains. Near the margin of the plateau, the valleys have become deeper, *e. g.* south-east of Bear Island. Moreover it seems probable that this low region may have been repeatedly submerged, and marine denudation has then lowered

and reduced all saliences, and the bottom of the valleys has been filled up by deposit of sediments. During the maximum extension of the ice-sheet of the first glacial period, there may have been much glacial erosion, especially near the margin of the plateau, if it stood much higher. Through the great valley south of Bear Island, a broad glacier may possibly have passed westward into the Norwegian Sea, being fed by the precipitation falling over the extensive region of the Barents Sea and the adjoining lands. This broad glacier may have greatly contributed to give the valley its present shape, and the detritus of the glacier may have been deposited on the bottom of the Norwegian Sea outside, which has thus to some extent been filled up, as may perhaps be indicated by the few soundings known from this region. Judging from what we know of other formerly glaciated lowlands, it seems hardly probable that the valleys have been excavated by the ice-sheet to any great extent in the interior of this flat region. It seems rather probable that during the later stages of the glacial period, the ground moraine has tended to fill up the depressions of the underlying ground, as has been the case for instance, to a great extent, on the North German lowlands[1].

However this may be, we cannot fail to recognize in the present sculpturing of the bottom of the Barents Murman Sea a striking resemblance to that of a subaërial region; and if this sea bottom were elevated above sea level it would form a rolling plain exhibiting much resemblance to the basins of the northern Russian rivers and of the great Siberian rivers, the Obi and the Yenisei, and also to some parts of the North German lowlands. But it has a much wider extension than the last-named, and there are greater differences of height, with deeper and broader valleys.

Continental Shelf. There seems to be no distinctly developed continental shelf in the Barents Murman Sea except to the north and north-west of Kanin Nos and Kolguyev, where a platform with depths from 30 to 80 m. extends between 100 and 200 kilometres northward. This platform is of an especially wide extent towards 71° N. Lat., 42° E. Long. Its slope is very gentle, about 1 in 2000 or even 3000. Its edge is probably situated at between 80 and 100 m. The slope outside the edge does not seem to be

[1] Cf. FELIX WAHNSCHAFFE, Die Ursachen der Oberflächengestaltung des Norddeutschen Flachlandes, 2nd edition, Stuttgart, 1901.

very steep as a rule, but is much intersected by depressions or submerged valleys. Off the north-west coast of Novaya Zemlya there are also indications of a continental shelf, but the soundings are few, and it is difficult to point out where, or at what depth, its edge is situated.

The main features of the present arrangement of the *suboceanic valleys* of the Barents Sea are evidently the following (see Pls. I, II). *The trunk valley* forming the entrance is the comparatively deep and broad channel, more than 450 m. deep, passing eastward south of Bear Island, between 73° and 74° N. Lat. To what depth the embouchure of the channel descends cannot at present be stated, owing to the fewness of the soundings in this region; and thus the base-level of erosion cannot be determined. The trunk channel — let us call it the *Bear Island Channel* — divides into several branches, *viz.*

1. *The Hope Island Channel.* The most northerly branch is a comparatively deep (410 m.) and narrow channel running towards the north-east, north, and north-west, east of Hope Island, between Edge Island and King Charles Land (Wiche Land). It probably forms a continuation of the Hinlopen Strait.

2. *The main branch of the Barents Channel* extends towards the east and north-east, off the west coast of Novaya Zemlya. Whether the main entrance to this long and crooked channel is in 72° N. Lat., 35° E. Long., or farther north in about 76° N. Lat. (see Pl. II), cannot at present be stated, owing to the fewness of the soundings. It seems probable that wherever the entrance may be, there is no direct communication between the greater depths (496 m.) of the main channel south of Bear Island, and the deep hollow (375 m.) west of Novaya Zemlya in about 44° E. Long. and between 73° and 76° N. Lat.; the channel originally connecting them may have been filled up to some extent with glacial detritus. Off the west coast of Novaya Zemlya the main channel has evidently many lateral branches, and if the sea bottom were to be uplifted some 200 or 250 m., we should here obtain a coast with long and narrow fjords. A long and very narrow valley extends towards the north in about 45° E. Long.[1] Many branches are given off eastward towards the coast of

[1] This branch seems to extend towards the strait between the Franz Josef Archipelago and Spitsbergen; whether, however, it is continuous with the depths of this strait, seems to me doubtful. West of Alexandra Land the Jackson-Harmsworth Expedition sounded 420 m. (230 fath.) and even 512 m. (280 fath.); but these depths are probably more or less continuous with the deep North Polar Basin, and may be separated from the deeper depressions of the Barents Sea by a ridge, little more than 200 m. deep, extending from the northern part of Novaya Zemlya towards King Charles Land and Spitsbergen (see Pls. I and II).

Novaya Zemlya, and a narrow branch seems to extend towards the south-east ending some distance north of Kolguyev. It seems difficult at present to decide whether this branch has originally been connected with the narrow channel passing along the south-west coast of Novaya Zemlya, which may have been partly filled up with moraines, or whether the latter channel has not rather drained through the Kara Strait into the deeper channel of the Kara Sea and there has been an ancient divide extending from Goose Land to Kolguyev. The latter explanation may seem the more probable, and in that case the Kara Strait is formed to some extent by the erosion of the river channel and later by glacial erosion. In about 70° 30′ N. Lat., 39° E. Long. there seems to be a branch passing towards the south-east, which might be a continuation of the Cheskaia Bay and the strait between Kolguyev and Kanin Nos.

3. *The Vardø Murman Channel.* The most southern branch extends southward from the Bear Island Channel to form a narrow valley, the *Vardø Channel,* up to 400 m. deep, along the coast of East Finmarken, and receiving a narrow tributary, from 100 m. to 200 m. deep, from the Varanger Fjord. It continues its course towards the south-east along the Murman Coast, gradually becoming shallower until it finally disappears. It seems, however, probable that the drainage area of the White Sea has formerly, when the whole region was elevated into dry land, had its outlet through this channel, which consequently at that time was in open communication with the deep depressions — up to 300 m. — of the White Sea.[1] The entrance to this large fjord has, however, subsequently been barred, chiefly by glacial drift, and possibly to some small extent has also been silted up still more recently by marine deposits. We have here on a large scale the same features as those of most of the Norwegian fjords (see later), *viz.* great depths in their interior parts, and barriers near their mouths and in the sea outside them. As this subject may possess special interest, it will be discussed in a later section, in connection with the Norwegian Suboceanic Channel, which exhibits similar features.

The submarine ridges and plateaus which seem to bar the submerged valleys in other parts of the Barents Murman Sea may have been formed in

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[1] There is naturally also a possibility that the White Sea originally drained in the direction of the present submerged valley extending southward into the continental shelf between 70° and 71° N. Lat., and between 38° and 40° E. Long.

a similar manner. We cannot at present determine the limits of the widest extension towards the north of the great ice-sheets in the region of the Murman Sea. Dr. RAMSAY's[1] investigations have shown it to be probable that the Kola Peninsula has had at least two glacial periods, and that during the first of these, the whole of the peninsula, as well as the Rybachi Peninsula (Fischerhalbinsel) and Kildin Island, were entirely covered by an ice-sheet, which was so thick that the directions of its motion could only to a limited extent be determined by the relief of the present land surface. It does not appear improbable that this ice-sheet extended far into the area of the present Murman and Barents Sea, especially if the sea bottom was more or less elevated into dry land. During this period, barriers may have been formed by glacial detritus far to the north of the present coasts; and I consider it possible, for instance, that the Vardø channel may to some extent have been filled up in this manner between 71° 30′ and 72° 30′ N. Lat., and its deeps have been separated from that of the Bear Island Channel.

It is a circumstance perhaps worth mentioning, that in the arrangement of the submerged valleys of the Barents Sea a longitudinal, northerly or north-northeasterly, direction and a transverse direction may possibly be recognized. The broad and very long valley, extending from about 71° N. Lat. and 36° E. Long. towards 76° N. Lat. and 44° E. Long, or still farther north, may form a broad longitudinal valley, extending, strange to say, very nearly as a northward continuation of the depression of the Baltic and the Gulf of Bothnia. Parallel to this longitudinal valley we have perhaps another, originally longitudinal valley, extending from the depression in about 71° 20′ N. Lat. and 28° E. Long. towards the Hope Island Channel in about 76° N. Lat. and 31° E. Long. The Kara Sea Channel along the east coast of Novaya Zemlya passes also in a similar direction although this may be more incidental. In directions more or less vertical to the great longitudinal valleys there are transverse valleys, evidently as a rule much narrower, and traversing the longitudinal ridges. The two possible channels between the two longitudinal valleys of the Barents Sea may belong to this system of transverse valleys, and similarly the many submarine side valleys off the

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[1] WILHELM RAMSAY, 'Über die Geologische Entwicklung der Halbinsel Kola in der Quartärzeit.' *Fennia,* vol. 16, No. 1, Helsingfors, 1898.

west coast of Novaya Zemlya. The Bear Island Channel may also originally have been a transverse valley, which now, however, has been much widened. It is an interesting coincidence, that the narrow Matotchkin Shar runs in exactly the same direction. I cannot help thinking that these great features of the surface relief of the bottom of the Barents Sea may have some genetic connection with differences in the tectonic structure of the underlying rocks, possibly caused by folds or dislocations of the Earth's cust.

Summary. Judging from what has been said above, and from the results of RAMSAY's investigations, I think the history of the recent changes of this region may have been as follows. In pre-glacial times, the bottom of the Barents Murman Sea was elevated[1] into dry land, and during this period of elevation, its present submerged valleys may already have been eroded to a great extent. How great the maximum of this pre-glacial elevation was, cannot be decided, as the soundings are not sufficiently numerous to trace the submerged Bear Island Channel down to its base-level of erosion on the continental slope towards the deeper regions of the Norwegian Sea. The elevation cannot have been less than 500 m., but may have been much more.[2]

The first glacial period then followed, with the widest extension of the ice-sheet. Whether the Bear Island Channel was at that time more or less filled by a glacier, cannot be decided, but it does not seem impossible.

This maximum glacial period was followed by a subsidence of the land, and during more or less stationary periods of the retreat of the ice-margin, barriers may have been formed across the valleys by the deposition of glacial detritus, perhaps in the sea outside the glacial margin. It is probable that the submerged Murman Channel (between the entrance to the White Sea and the Vardø Channel) was filled up, to a great extent, during the latter part of this first glacial period. According to RAMSAY, the motion of the ice-sheet was probably in a north-easterly direction on the Murman Coast at this time, *i. e.* athwart the channel; but farther east, the motion followed more or less

[1] The expressions, elevation, subsidence, submergence, etc. are here used for the sake of simplicity, without inferring whether the changes were due to vertical movements of the land or the sea.

[2] The surface relief of the bottom of the Barents Murman Sea, seems to resemble that of an ancient continental surface that had been much worn down, but which might recently have been somewhat uplifted, and again dissected before it was submerged.

the direction of the White Sea Channel. On the one hand an ice-sheet moving athwart a valley may have a tendency to fill it gradually up with a ground moraine; and on the other hand, when the margin of the ice-sheet retreated to the present Murman Coast, and there passed a stationary period, the submerged valley outside may have been filled up by the deposition of glacial detritus from this ice-sheet, as well as from the glacier passing through the White Sea Channel.

In the interglacial period there was a general depression of the land, and a partial submergence of the present land-surface, for instance on the Rybachi Peninsula (Fischerhalbinsel) and Kildin Island, to a height of 90 or 100 m. above present sea-level. It seems to me uncertain whether the magnitude of this interglacial submergence differed much at different localities of this region.

It seems probable that after this greatest submergence, a period of elevation occurred, during which the valleys were probably to some extent reëxcavated. This period was followed by the latest glacial period,[1] during which the margin of the ice-sheet, according to RAMSAY, never reached the greater part of the Murman Coast (see Pl. II), and the glacier of the White Sea ended near the entrance to that sea, very nearly at the point where we now have the shallowest part of the barrier[2]. During this period the Murman Channel was naturally refilled. If RAMSAY'S map of the extension of the latest ice-sheet be correct, this refilling cannot to any great extent have been due to glaciers on the Murman Coast, as they did not reach the coast; but it may chiefly have been due to the White Sea glacier. It seems probable that during the greater part of this glacial period, the sea-level was much the same as it is at present, and that the channel along the Murman Coast was refilled by the submarine deposition of glacial detritus. At the end of the White Sea glacier, terminal moraines were probably formed, and it is possible that the shallow narrowing of the submarine channel near the eastern Murman Coast north of Lat. 67° N. (see Pl. II), is a remnant of the terminal moraine formed during the farthest extension of the glacier during this period. It is situated just a little south of the point where RAMSAY has placed the limit of

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[1] The possibility that the Kola Peninsula may have had several glacial periods is hardly excluded, although RAMSAY's investigations seem to indicate only two.

[2] Cf. RAMSAY, l. c., map, p. 118, and our bathymetrical chart, Pl. II.

the farthest extension of the ice-sheet on the coast. The ridge (47 m.) across the narrowest part of the entrance to the White Sea, is possibly a second terminal moraine, formed during a later stationary period of the retreat of the ice-margin.

At the end of the latest glacial eriod, a subsidence with partial submergence of the present land-surface occurred, but this submergence was not so great as the interglacial one. On the Rybachi Peninsula, the submergence reached a height of about 70 m., and on Kildin Island about 50 m. The magnitude of this submergence differed according to the situation of the coasts (cf. RAMSAY's map, l. c., p. 132).

After this a new elevation of the land probably occurred, and it is possible, according to my view, that some part of the present sea-bottom again rose into dry land, and that in the glacial deposits filling the original valleys, new river channels were incised, which still exist as submerged valleys. This question will have to be finally decided by future investigations of the sea-bottom.

In post-glacial times, we had a final subsidence with partial submergence of the land, smaller than the late glacial submergence, and attaining a height of only 21 or 22 m., on the Rybachi Peninsula and Kildin Island.

This subsidence was followed by an elevation of the land to present sea-level.

I think that, roughly speaking, these may be the main features of the recent history of this region. It is seen that the succession of subsidences and elevations is to a great extent similar to what is now generally accepted for the whole of northern Europe. There may have been more glacial periods, and more oscillations of sea-level, than assumed above; but this will make no great difference. The chief point of interest for our present purpose is that there has been great vertical oscillation of sea or land, and that the bottom of the Barents Murman Sea must once, at no very remote period, have been a dry land-surface.

V. THE CONTINENTAL SHELVES, AND SUBMERGED VALLEYS AND FJORDS OF NORWAY.

The continental shelf of the Norwegian coast is very irregular, and differs much in its form from the apparently very level Siberian continental platform, although, to some extent, it may be said to form a continuation of the latter. As the features of the Norwegian continental shelf are very peculiar, and may throw some light upon the history of continental shelves in general, I will offer it some special attention. No other shelf of the northern seas has been so well surveyed, thanks to 'Norge's Geografiske Opmaaling'. The manner in which we look at and describe a continental shelf, is naturally greatly influenced by the theory we have formed of its origin. If, for instance, according to current theories, we assume the continental shelves to have been formed by marine denudation or sedimentation during a definite, long period of lower sea-level, and slow, gradual submergence of the coast, we shall naturally look for the undisturbed continental shelf at a certain depth, determined by this previous situation of sea-level. Where we find the general floor and the edge of the shelf situated at other depths above or below, we say that the shelf has been subject to alterations since its prime formation. If we approach the Norwegian continental shelf with preconceptions such as these, we shall be much disappointed, for we shall hardly be able to find any definite depth at which the edge (or the general floor) of the shelf is situated in preference to any other. As a rule, the depth of the edge below sea-level differs much between 80 m. and 300

m.[1] The whole formation exhibits striking differences in the different regions, and along the whole of the western and southern parts of the coast, from the Nord Fjord, or the Sogne Fjord, to the Christiania Fjord, it is, as a rule, almost entirely absent, if we do not consider the platform of the North Sea as the continental shelf of southern Norway, and the submerged Norwegian channel as a fjord cut into this shelf. Along the northern and eastern coasts of Finmarken, the continental shelf is also very indistinctly developed, although the bottom of the shallow Barents Sea might be considered as an extensive shelf. Even at those places where the shelf is most level and most sharply defined, *viz.* off Søndmør-Romsdalen, and off Lofoten and Vesteraalen, the depths at which the edges are situated vary much, from 60 m. to 200 m. Let us therefore try to describe the Norwegian continental shelf with as few preconceptions as possible and let us first only consider the Norwegian coast north of 62° N. Lat.

A fairly detailed bathymetrical chart of the Norwegian coast, and the sea outside (see Pl. XI), shows that the great valleys and fjords of the land inside are very often continued as submarine valleys or fjords for long distances across the submerged continental shelf, generally barred by several transverse ridges or thresholds. A remarkable universal feature of the submarine fjords is that their deepest hollows, often descending to depths of more than 400 m. and in a few cases of more than 500 m., are as a rule situated near the outer coast-line, while the fjords become considerably shallower towards the edge of the continental shelf, where they even often entirely disappear, or are at any rate separated from the depths of the ocean outside by a barrier. At some points the submarine fjords traverse the continental shelf as continuous depressions, and open out at the edge of the slope, forming distinct incisions in the continental slope. But it is a striking fact that these fjords are not as a rule traceable along the continental slope much beyond the 400 metres line, and seldom even as far. The submarine continuation of the Ofoten Fjord and Vest Fjord south of Lofoten (in about 67° N. Lat.), and that of the Trondhjem Fjord and the Folden Fjord (just north

[1] Mr. WILFRID HUDLESTON says in his instructive paper 'On the Eastern Margin of the North Atlantic Basin' (*Geol. Mag.*, London, vol. VI, 1899) that the 'general Norwegian submerged shelf has its edge near the 200-fathom contour'; but this statement is hardly correct. It is only at few places, that the edeg of the shelf is situated as deep as 360 m. (200 fathoms) below sea-level.

of 64° N. Lat.), are splendid examples of such fjords. At such places, the edge of the continental shelf is situated comparatively deep. Between the submarine fjords and valleys, the continental shelf is naturally best developed, having the highest level and exhibiting the most sharply defined edge. The Lofoten-Vesteraalen Islands and the Søndmør-Romsdalen coast, the two highest and most mountainous portions of the Norwegian coast with the steepest mountain slopes, have the most regularly developed continental shelves, with the shallowest water, and exhibit in this respect a striking difference from the rest of the Norwegian coast.

As characteristic features of the Norwegian continental shelf, north of 62° N., might perhaps be mentioned the fact that the narrower the shelf, the higher and more regular is its level (*e. g.* Romsdalen and Vesteraalen-Senjen); and farther, that the broadest and deepest continental shelf is generally situated outside the lowest coast, with the lowest land inside (*e. g.* the Trondhjem district, Helgeland and Finmarken).

a. THE CONTINENTAL SHELF OFF LOFOTEN, VESTERAALEN, AND FINMARKEN.

The Lofoten-Vesteraalen submarine shelf forms a level platform, bordering the Lofoten-Vesteraalen Islands, and having a wide westward extension, towards the open ocean. The width gradually decreases towards the north-east from about 87 kilometres (47 naut. miles) off Værø and Røst, to about 18 kilometres (10 naut. miles), or less, off the northern end of Andø. Compared with the continental shelf off the coast north and south of it, this platform is little incised by submarine fjords or depressions in its southern part, off the Lofoten Islands, where its surface is comparatively very level (see longitudinal Section). Off Langø and Andø in Vesteraalen, and off Senjen (farther north), *i. e.* between Lat. 68° 40′ N. and 69° 45′ N., where the shelf is narrower, its general floor is situated at its highest level, which is between 60 m. and 80 m., and its edge is situated at about 80 m. (see Sections 13, 14, 15), and in Section 12 (the Senjen Bank) perhaps even at about 62 m. This highest and narrowest portion of the platform is dissected by several comparatively deep submarine fjords, dividing it into several banks. We may distinguish 4 such flat banks in this region, which have extremely uniform depths, and their edges situated very nearly at the same level of about

80 m. or a little less, *viz.* the Senjen Bank off Senjen, the Andø Bank off Andø, and two banks off Langø in Vesteraalen.

The Malangen Bank off Kvalø, north-east of Senjen, has also very similar depths in its inner part; but the general floor slopes seaward, and its edge is situated somewhat deeper, at about 140 m. (see Section 11 Pl. XII). These five banks, but for the intervening submarine fjords, would form an extremely level plain, extending along the coast over a distance of about 230 kilometres (128 naut. miles), with widths of between 20 and 50 kilometres. Their general floor is, as a rule, situated between 70 m. and 80 m. below sea-level, but at several places submarine rocky hills rise above the plain to heights of only 56 m. (31 fathoms) or even 38 m. (21 fathoms) below sea-level, *e. g.* Sørskallen, 31 kilometres (17 naut. miles) off the southern end of Langø. They rise about 20 m. or 30 m. above the general floor.

The transverse sections across the continental shelf at these five banks (see Sections 11, 12, 13, 14, and 15) are extremely like each other, and exhibit two distinct levels. Near the coast there is a higher level, the *coast platform* (Strandfladen, see later) descending only to some few metres (10 or 15 m.) below sea-level, and covered with numerous shoals, sunken rocks and skerries, dangerous to navigation. From the edge of this coast platform, extending from 2 kilometres (Section 14) to 20 kilometres (Section 11) from the coast, there is an abrupt and very steep descent, generally to the bottom of a very narrow submarine fjord or depression with depths of between 100 and 200 m. (Sections 11, 12, 14, 15). Then comes the very nearly horizontal surface of the continental shelf situated at between 70 m. and 80 m., sometimes a little higher or a little deeper. The *continental slope* descending from the sharp edge of the shelf (situated between 62 m. and 83 m.) towards the oceanic abyss, is exceptionally abrupt in this region, the slope varying between 1 in 11·3 or 5° 30′ (in Section 15) and 1 in 6·9 or 8° 40′ (Section 14); at some places, indeed, the slope may be 1 in 4 or 14° 30′, and at one place (70° N. Lat.) even 1 in 3 or 20°. The steepest part of the continental slope is generally between depths of 200 m. and 1000 m. Below 1500 m. or 2000 m. the slope becomes much gentler towards the floor of the ocean.

The submarine fjords in the region north of Andø, form comparatively deep incisions in the continental shelf, and may descend to depths of 230 m.

below its general floor, and in some few cases even considerably deeper. The And Fjord, between Andø and Senjen, is a deep submarine fjord, at one place 500 m. deep, forming an incision of 400 m.'s depth in the surface of the shelf. It is separated from the oceanic deep outside by a high, narrow ridge, with depths of less than 260 m. North of Senjen there is another deep (about 430 m.) and well-defined submarine fjord, the Malangen Submarine Fjord, separated from the oceanic deep by a similar ridge covered by about 260 m. of water. At one place, *viz.* the Ersfjord Deep, this fjord has a depth of 650 m., situated, however, inside the outer margin of the coast platform. Farther north, in 70° 10′ N. Lat. there is a third, shallower, but also well developed, submarine fjord, about 365 m. at its deepest, and also barred at its mouth by a ridge, about 255 m. below sea-level.

Between the mouths of the And Fjord and the Malangen Submarine Fjord, there is a deep and sharply-defined embayment, or incision, in the steep continental slope. North-west of Andø there is a similar, but still longer and narrower incision. North and south of these places, the continental slope has a few similar, but less marked, incisions. These depressions, which bear a strong resemblance to river valleys, are distinctly marked down to the 1000 metres contour; and how much deeper they reach it is impossible to say, as there are no soundings. It would be of great interest to know whether they actually are ancient valleys, formed by erosion, descending the continental slope to these great depths, and consequently formed when the land stood so much higher. But as far as I can see, nothing can be said with certainty on this point. It is a strange circumstance that the depressions are not situated at the mouth of the submarine fjords, but rather between them. It is not, perhaps, altogether impossible, that embayments might be formed between the fans or, as we might call them, glacial deltas formed by glacial drift in front of the mouth of each fjord; but it is hardly probable that these embayments would form such deep, narrow incisions as, for instance, that north-west of Andø. It is not impossible that this incision is actually the original entrance to the sound between Andø and Vesteraalen, which has been filled up nearer land. The possibility that similar depressions might be formed by dislocations (trough-faults), does not, however, seem to be less probable; for this is just a region of comparatively recent dislocations, by which the Jurassic formation of Andø has been

rescued from obliteration; and the faults have to a great extent a similar direction.

South-west of Langø in Vesteraalen, the general floor of the continental shelf slopes somewhat (see Longitudinal Section), and for some distance is situated at a uniformly lower level of between 115 m. and 140 m. (see Sections 16, 17, and 18); and its edge, as a rule, is situated at about 120 m. or 130 m. Farther to the south-west, the floor of the shelf slopes gently to a depth of about 230 m., where it forms a more sudden descent towards the bottom of the broad submarine fjord off the mouth of the Vest Fjord (see Longitudinal Section). Off Røst (Section 19), the shelf slopes gently seaward to its edge, situated at 230 m. below sea-level. The continental slope from this edge to a depth of 2106 m. is 1 in 26·4 or about 2°; while along the sections farther north, the continental slope is steeper, *viz.* between 1 in 15 or 3° 50′ (in Section 18) and 1 in 6·8 or 10° (in Section 17). The features of these sections are very much like those of the sections farther north. First, near the coast, there is a narrow *coast platform* only slightly below sea-level, from 2·5 to 8 kilometres broad; next, a steep descent to a deeper submarine fjord or hollow; and then the very flat floor of the continental shelf, which, in its northern part, is very nearly horizontal (Sections 16, 17, and 18), but farther south slopes gently — about 1 in 590 or 5′ 50″ (Section 19) — towards the edge, where the continental slope forms an abrupt descent towards the oceanic abyss. In the southern part of the Lofoten-Vesteraalen shelf, south of Langø, the submarine fjords and hollows form only shallow incisions of no more than between 70 and 100 m. below the general floor of the platform, and descending to depths of between 210 m. and 260 m. below sea-level.

North of 70° N. Lat., the general floor and the edge of the continental shelf gradually sink to greater depths, while the shelf at the same time becomes broader. It has been mentioned before that the edge of the Malangen Bank is situated at about 140 m. although its inner portion is very nearly at the same level as the banks farther south. Farther north, off Grøtø, the floor and the edge of the shelf are situated still deeper. North of this region, the edge of the continental shelf perhaps slopes gradually down to a depth of about 450 m., as it does at the mouth of the Bear Island Channel; and it trends northward or north-north-west, while the coast trends

eastward. The continental shelf thus widens out to form an extensive shallow sea to the north of Finmarken, uniting Norway with Bear Island and Spitsbergen. On this extensive platform there are two great submarine fjords, dividing it into several banks or plateaus. West of Sørø, there is a great submarine fjord — we might call it the Sørø Submarine Fjord — which is a continuation of the Kvænangen Fjord and the Alten Fjord, extending first north and then north-west (see Section B). The Vardø Channel, uniting with the Bear Island Channel, forms a similar great submarine fjord (see p. 31). They both have depths exceeding 400 m. (425 m. and 533 m.), and they are perhaps less barred in their outer parts by thresholds, than most submarine fjords farther south. The great continental shelf between Finmarken and Bear Island is situated, on the whole, comparatively deep. The bank west of the Sørø Submarine Fjord has, at its highest part, a depth of 145 m. (Section 10), but seaward slopes regularly down to a depth of 327 m., at an incline of 1 in 857 or 4′. The depth of the edge, and its distance from land, cannot be decided, as there are no soundings.

The plateau (Section 9) between the Sørø Submarine Fjord and the Vardø Bear Island Channel is situated still deeper, with its highest part at 229 m. and sloping northward to about 283 m. near the edge of the Bear Island Channel. The platform or ridge on which Bear Island and Hope Island are situated, on the other side of this channel, is covered by less water, the depths being apparently largely between 60 m. and 90 m., or similar to those of the Andø-Senjen continental shelf, and at several places even less than 40 m.

Sections 10 and 9 exhibit an interesting difference as regards the *coast platform*, which is altogether absent in the latter section. In Section 10, the coast platform is present, but is situated deeper — at about 30 m. or 40 m. — than it generally is farther south; and in this region it has very few saliences approaching sea-level. Along the coast from Sørø to Magerø, there is a narrow platform with depths generally between 40 m. and 90 m., and with a fairly well-defined edge at about 80 or 90 m. A similar platform may also be traced along a greater part of the coast east of the North Cape, *e. g.* at Nordkyn, and along the north-east coast of the Varanger Peninsula (Section 8); at places it may be 10 or 12 kilometres broad. It seems difficult to decide whether this platform has originally been a part of the continental shelf, or whether it corresponds to the coast platform, which is here

situated deeper. The latter seems more probable. It is a striking fact that the sudden disappearance at Sørø of the coast platform of the ordinary type (situated near sea-level), and the occurrence of the deeper, narrow platform mentioned above, east of this place, coincides exactly with the boundary between the higher, mountainous land south-west of the Kvænangen Fjord and the Alten Fjord, and the lowland of Finmarken, east of these fjords.

b. THE SØNDMØR-ROMSDALEN CONTINENTAL SHELF.

This shelf, the edge of which is called *Storeggen*, bears, in several respects, a great resemblance to the Lofoten-Vesteraalen shelf. Its surface is extremely level, and is still less incised by submarine fjords and depressions than that of the former; but it is situated on the whole somewhat deeper. Its width from the outer coast-line to the edge is between 60 kilometres (at its narrowest parts) and 80 kilometres. By two transverse shallow depressions, or submarine valleys, the Søndmør-Romsdalen shelf is divided into three sections (see Longitudinal Section) standing at somewhat different levels, the middle one being the highest, with its shallowest portion at the Langgrund Bank (Section 32), off the coast between the Stor Fjord and the Romsdal Fjord (*i. e.* between Aalesund and Molde). The nearly horizontal general floor of the shelf in this region lies between 85 m. and 100 m. below sea-level (see Section 32). The sharply defined edge of the shelf is situated at about 132 m. Both southwest and northeast of this place, the general floor of the shelf lies at lower levels. The sections 31 and 33 pass across the same bank of the shelf (see Longitudinal Section), one on each side of the former section. In Section 31 the general floor lies between 120 m. and 140 m., with a higher portion near the coast (at 73 m.). The sharply defined edge is situated at 136 m. In Section 33 the floor is more irregular; its shallowest portion is situated about 35 kilometres from the coast, with a depth of about 75 m. From this place, the floor slopes towards the edge, which is situated at about 154 m. below sea-level. In Section 34, across the south-western part of the shelf, its nearly horizontal general floor lies between 170 and 200 m. with a limited higher portion in the middle, rising to 139 m. below sea-level. In this section the edge of the shelf is situated at about 180 m. Towards the west, the shelf is bounded by a steeper slope towards the entrance to the Norwegian Chan-

nel. The edge of the shelf is here situated at about 198 m. (see Longitudinal Section). In Section 30, across the north-eastern portion of the shelf, the general floor slopes gently from a depth of about 64 m. near the coast (with an isolated projection rising to within 49 m. of sea-level) towards the edge, situated at 150 m. below sea-level.

The general character of these sections across the Søndmør-Romsdalen submerged shelf is much the same as that of the sections across the Lofoten-Vesteraalen shelf. Near the coast there is first a *coast platform*, consisting of shoals and sunken rocks, situated slightly below sea-level, and with deeper water of about 60 or 80 m. between them, from 5 to 17 kilometres broad (Section 32); next, a very steep descent, generally to the bottom of a narrow submarine depression or fjord, and lastly, the level surface of the continental shelf. The *continental slope* is not so steep as outside the Lofoten-Vesteraalen shelf. At its steepest, in Section 30, the slope is about 1 in 16 or 3° 35′ (between the depths of 150 m. and 779 m.). The slope decreases farther to the southwest, to about 1 in 43 or 1° 21′, in Sections 32 and 33, and about 1 in 54 or 1° 3′ in Section 34.

The most prominent depression on the Søndmør-Romsdalen shelf is *Bredsunds-Dybet*, a comparatively shallow submarine fjord, which has several branches, and forms a submarine continuation of the deep Stor Fjord. Bredsunds-Dybet is situated near the coast; but even at its deepest (286 m. in 62° 33′ N. Lat. and 5° 15′ E. Long), it forms a depression of no more than 210 m. below the surface of the platform, the highest parts of which, at that place, are situated at a depth of about 75 m. on both sides of the fjord. At most places the incision made by this channel is very much shallower, as a rule no more than 140 m.; and we see that although its horizontal shape on a map bears much resemblance to that of an ordinary fjord, there is a striking difference as regards its vertical shape. In the Stor Fjord there are depths of at least 400 m. and probably much more; in the Volden Fjord (a branch of it) the depth is even 720 m., and the sides of the fjord ascend to heights of 1000 m. and more. The highest mountains in the neighbourhood rise to between 1400 m. and 1800 m. Thus the fjord forms an incision of more than 1000 m. below the general floor of the land-surface, and 1800 or 2000 m. below the level of the highest mountains. Bredsunds-Dybet gives off branches running seaward; but they are very shallow, and gradually dis-

appear at no great distance from land, and only half-way to the edge of the shelf.

It is a remarkable and very interesting feature in the arrangement of Bredsunds-Dybet that its depressions run chiefly in two distinctly different directions, *one longitudinal direction*, running more or less parallel to the main direction of the coast, or a trifle more easterly, and one *transverse direction*, forming an angle of nearly 90° with the first. The depressions branching off seawards, the middle portion of the main channel itself, as well as the channels coming from the fjords inside, follow more or less the latter direction. The very same arrangement is exceedingly conspicuous in the shape of the fjords of the Norwegian coast from Stat to the Trondhjem Fjord and farther northward (see later). Good examples of longitudinal fjords, chiefly following two slightly diverging directions, are, — the Røvde, the Vartdal, and the Stor Fjords in one line, the Molde and Fanne Fjords in one line, the Lang Fjord and the Ise Fjord (branches of the upper part of the Romsdal Fjord), and the Kvernes, Fei and Aarsund Fjords within Kristiansund, and the Aast Fjord within Hitteren; but the best specimen of longitudinal fjords is perhaps the straight channel, about 150 kilometres (83 naut. miles) long, passing from Hustadviken, west of Kristiansund, inside Smølen and Hitteren, forming Trondhjems-Leden, and ending in the Skjørn Fjord. The Beistad Fjord and Lake Snaasen are also situated on the same line. The sound between Frøien and the Fro Islands, the Frøi Fjord (between Frøien and Hitteren), the Vals Fjord, Koet, and Aa Fjord in one line, the Bjugn Fjord, and also the upper part of the Trondhjem Fjord, all run exactly parallel to the same line. Examples of the *transverse direction*, vertical to the direction of the coast, are to be seen in Sule Fjord (the lower part of the Stor Fjord), Volden Fjord, Jøring Fjord (branches of the Stor Fjord), the upper part of the Stor Fjord, Ramsø Fjord (between Smølen and Hitteren), the mouth of the Trondhjem Fjord, etc., etc.

The longitudinal direction is nearly parallel to the axis of the mountains from the Søndmør-Nordfjord mountains along the Dovre, and also parallel to the divide between the so-called Nordenfjeldske and Søndenfjeldske Norway.

There is little doubt but that this remarkable arrangement of the fjords stands in some genetic relation to the tectonic structure of the land, the direction of the longitudinal fjords and valleys probably being determined by

longitudinal mountainfolds, dating from the formation of the present Norwegian and Caledonian mountain chains. In the synclines of these folds, softer rocks have been depressed between the harder foundation rocks in the anticlines, and have offered less resistance to erosion, especially that of running water, but also to glacial erosion. It is a very significant fact that the same longitudinal and transverse directions are also found in the arrangement of the submarine fjords of the continental shelf outside the coast, as I shall discuss later on.

The surface of the Søndmør-Romsdalen shelf is not much incised by depressions near its edge (see Longitudinal Section), and resembles in this respect the southern part of the Lofoten-Vesteraalen shelf. The edge itself exhibits no great embayments, but from its north-eastern part, off the Romsdal Fjord, a number of narrow valleys seem to descend the continental slope (which has its steepest incline in this region) at any rate as far as the 800 metres contour. Whether they descend deeper cannot be decided at present, as unfortunately the soundings go no farther. These valleys have possibly been formed by erosion, and may indicate that the continental shelf once stood at that height above sea-level.

c. THE CONTINENTAL SHELF OFF THE COAST BETWEEN ROMSDALEN AND LOFOTEN.

One characteristic feature of this region is, that while the floor of the submarine shelf is on the whole much less level, and situated at greater depths, than the floors of the Søndmør-Romsdalen shelf and the Lofoten-Vesteraalen shelf, the edge of the shelf is much less abrupt in descent, and is situated at a much greater distance from land, the width of the shelf being between 190 and 260 kilometres (at Section 23). The continental slope is much gentler, and the deep sea outside is considerably shallower than that north and south of the region. This is clearly seen on the bathymetrical chart, Pl. XI, where the isobaths of depths greater than 400 and 500 m. diverge north of 64° 30′ N. Lat., and their distance from land increases. The submarine shelf and the continental slope outside, form, as it were, a fan of slight slope, projecting far into the deep Norwegian Sea, and bearing some resemblance to the delta or the alluvial fan of a river. At some places, *e. g.* at our Section 25, the shelf has no very distinct edge; the sea bottom

slopes more or less gradually from the inner, highest part of the shelf towards the greater depths of the ocean, without any abrupt descents. Where a more sharply defined edge is found, *e. g.* in Sections 29, 28, 27, 26, 24, 23, 22 and 21, it is situated at comparatively great, and very varying depths, *viz.* 238, 240, 269, 330, 250, 278, 350, and 226 m.; and if we take Sections F, E, D, and C, along the bottom of the submarine fjords traversing the shelf, we find the edge at still greater depths, *viz.* 280 m., 428 m., 368 m., and 460 m. The large submerged fjords, with their very great extension, form a very prominent feature of the surface-relief of this part of the submarine shelf. Like the depressions of the Lofoten-Vesteraalen and the Søndmør-Romsdalen shelves, they certainly have their greatest depths, of between 450 m. and 510 m., near the land; but they nevertheless traverse the whole breadth of the platform as more or less continuous channels, opening out into the deeper sea outside, in this respect differing from the above-mentioned depressions. The bottom of the channels forms also, on the whole, a very level plane (cf. especially Sections C and D). Three different systems of submarine fjords may easily be distinguished, *vis.* the well defined and comparatively narrow submarine fjord with several branches, between 64° and 65° N. Lat., which is a continuation of the Trondhjem and Folden Fjords, the broad and deep submarine continuation of the Vest Fjord, south of Lofoten, and between them the broad system of less distinctly defined submarine fjords off Helgeland. Between the three large submarine fjords, the sea-bottom is elevated to form two extensive flat banks, with depths of less than 300 and 200 m. A part of the southernmost bank, called the *Halten Bank,* rises above the 200 metres contour, with depths of less than 100 m. (Section 25). It is a striking feature that the most elevated parts of these banks are situated along a slightly curved line, running from the shallowest banks of the Søndmør-Romsdalen submarine shelf (the Langgrund Bank and the Bogrund) to the Lofoten Islands; and nearly parallel to the direction of the coast, as well as to that of the longitudinal valleys of Nordland, and to the axis and divide of the highest mountains along the boundary between Norway and Sweden.

The transverse sections across the continental shelf between Romsdalen and Lofoten exhibit, as a rule, the same general features as those described above. Near the coast there is a coast platform — descending only some few

metres below sea-level — which is especially well developed in this region, being from 30 to 60 kilometres broad; then a steep descent to the bottom of a submarine fjord, or hollow, near the coast; and lastly, a less steep ascent again to the highest portion of the continental shelf, which is unusually broad, and has a very gentle slope towards its edge.

But the longitudinal section and the transverse sections show that neither the general floor, nor the edge of the shelf, is situated at any definite level, and perhaps still less so than in the parts of the Norwegian shelf described before. It seems, however, as if three different, more or less distinct levels might be made out, *viz.* (1) the level of the bottom of the submarine fjords, of between 400 m. and 500 m., (2) the level of the shallower parts of the banks between the submarine fjords, between 250 m. and 200 m., only at some few places less (*e. g.* the Halten Bank), and (3) the level of the coast platform (between 40 or 50 m. above sea-level and 20 or 30 m. below sea-level).

(1.) The level of the bottom of the great submarine fjords — we might call it a *base-level of the platform* — is so uniformly situated at depths between 400 m. and 460 m., at some few places descending to 510 m. and 514 m. (Sections D and E), and the bottom of the fjords slope on the whole so slightly and so regularly from the coast towards the edge of the platform, that on looking at the sections (especially C and D, but also E) it must at once appear probable that the bottom of these fjords indicates the base-level of erosion during some long previous period of elevation of the land. If not, there seems to be little reason why the bottom of these different submarine fjords, situated at such great distances from one another, should now lie so very nearly at the same regular level. This impression is greatly strengthened by comparing sections of submarine fjords in other regions. It seems a striking coincidence that the beds of the Vardø-Bear-Island Channel, and the Barents Channel, the Sørø Submarine Fjord, and the mouth of the Norwegian Channel, are all situated almost exactly at the same level. General characteristic features of these submarine fjords or channels are, that the deepest hollows in their interior parts, near the coast, descend to depths of between 430 m. and 533 m., the barriers between the deep hollows ascend to about 280 m. or 300 m. below sea-level, the general level of the bottom in the outer part of the fjords is situated at depths of between 500 m. and 405 m., and the bottom of the fjords at their mouths on the edge

of the continental shelf is situated at similar depths. The following table gives these characteristic depths of the various great submarine fjords.

	Deepest Hollows near Coast	Depth of Barriers between Hollows	General Level of Outer Portion	Depth of Edge of Cont. Shelf at Mouth of Fjord
Vardø-Bear-Island Channel (Section A)[1] . . .	533 and 430 m.	225 and 284 m.	500 m. (?)	500 m. (?)
Sørø Channel (Sect. B) .	501[2] and 425 „	330 and 290 „	480 „ (?)	500 „ (?)
Ofoten Submarine Fjord (Section C)	448 and 424 „	267 „	458 „	460 „
Helgeland Submarine Fjord (Section D) . .	510 and 476 „	310[3] „	440 „	368 „ (?)
Trondhjem-Folden Submarine Fjord (Sect. E)	514 and 488 „	329 and 287 „	405 „	428 „
Norwegian Chann. (Sct. G)	700 „	273 „	410 „	404 „

The Smølen Submarine Fjord (Sect. F) is not great, but is very regular; it is interesting because the general floor of its bottom seems to be situated very nearly at the same level as the barriers between the hollows of the other submarine fjords. On the whole, the above table might seem to indicate that the general depths of the submarine fjords have a tendency to increase northward.

While mentioning this base-level of the Norwegian continental shelf, it may be of some interest to draw attention to the fact that the deepest parts of the ridges between Scotland, the Færoes, Iceland, Greenland and Baffin Land, seem to be situated at very similar depths, as the following table will show.

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[1] After the description (pag. 31) of the Vardø-Bear-Island Channel had been printed, I have found, on Generalkart B 14 published by *Norges Geografiske Opmaaling* in 1902, a sounding of 533 m. in the deep hollow off Vardø. On the chart, No. 155, of the Barents Sea, published by the *Reichs-Marine-Amt,* Berlin, 1901, I find several deep soundings in the Bear-Island Channel, 535 m. in 73° 22′ N. Lat., and 20° 10′ E. Long., and 548 m. in 73° 10′ N. Lat., and 21° 12′ E. Long. These soundings were seen too late to be recorded in the chart Pl. II.

[2] This deep hollow is situated between the islands, and is more like that of a continental fjord.

[3] Nearer land there are higher barriers (see Section D), but they are situated between islands, and may be considered as belonging to the coast platform.

	Greatest depths
Wyville Thomson Ridge . .	480 and 580 metres
Færoe-Iceland Ridge	475 „
Iceland-Greenland Ridge . .	470 and 550 „ (?)
Greenland-Baffinland Ridge (Across Davis Strait) . . .	500 (?) „

The soundings on these ridges are not very numerous, and it is therefore very probable that more soundings would give smaller, and still more uniform depths for the deepest parts of these ridges.

(2.) The following table giving the depths of the highest parts of the shelf, its general floor, and its edge in the sections across the banks between the submarine fjords, will perhaps give better than words an impression as to how far these banks may be considered to indicate a definite level.

	Depths in Metres of				
	Highest Parts	General Floor	Edge	Greatest Depression	
				Near Land	On the Shelf
Section 21	188 and 205	260	220 (or 287)	375	318
Section 22	235	of higher part 240 of outer part 360	between 340 and 370	369	416
Section 23	335	about 400	278	390	476
Section 24	120	290	250	395	316
Section 25	102	about 250 (?)	293 (?)	488 and 452	
Section 26	134	about 250	between 320 and 348	470	263
Section 27	154 and 162	inner part 165 outer part 230	269	300 and 309	
Section 28	203	220	240	295	
Section 29	183	250	238		271

We see that the level of the general floor, as also the depths of the highest parts and the edge, differ much at the various places; but on the whole, both the general floor and the edge of the banks between the submarine fjords have perhaps a tendency to approach a mean level of between 220 m. and 260 m.; a level which is somewhat higher than

the barriers of the submarine fjords (generally between 267 m. and 290 m., see p. 49).

(3.) The *Coast Platform* or *Strandfladen* (*i. e.* shore plane), as it has been called by Norwegian geologists (Dr. H. REUSCH), is a universal and highly interesting feature of the morphology of the whole Norwegian coast from Lindesnes to North Cape,[1] but it is especially broad and well developed along the coast of Nordland (from Romsdalen to Lofoten) where, as stated by Prof. VOGT (l. c.), it has an average breadth of 40 or 45 kilometres (25 nautical miles), if we also include that part of it which is now elevated above sea-level. At several places, *e. g.* off Vel Fjord, Alsten Island and Dønna, Tomma and Trænen, it is even 50 kilometres wide or more; and at Hitteren, Frøien, and the Fro Islands its width is perhaps 60 kilometres (34 naut. miles), It forms the nearly continuous belt (Skjærgaard) of thousands (or ten thousands) of skerries, sunken rocks, and shoals extending far out to sea, and situated very nearly on the same level, differing by only some few metres above or below present sea-level. Near the actual coast-line, the coast platform is seen as a low land much intersected by fjords, and fringed with low islands, extending seawards at the foot of the declivity of the mountainous highlands within (see Illustrations, Pls. V, VI). More or less solitary rocky hills surmount the low platform at many places (see Pl. V, figs. 1, 4; Pl. VI, fig. 1).

If it were not for the many sounds and fjords dissecting the now submerged part of the coast platform and separating the numerous skerries and shoals, it would form an extremely level and regular plain (see Sections, Pls. XIV—XVI), even more level than the floor of the continental shelf outside, from

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[1] Several Norwegian geologists long ago drew attention to the „low fore-land" and low „Skjærgaard" which form such characteristic features of the coast morphology of Norway *e. g.* Prof. H. MOHN, *Nyt Mag. for Naturv.*, vol. 22, Christiania, 1877, and even much earlier authors. Prof. W. C. BRØGGER, who accompanied us on board the Fram, as far as Tromsø, on our way out, had some opportunity, during the voyage along the northern coast of Norway, of studying the phenomenon. The existence of the nearly horizontal level of this platform especially at Brønøsund, where it is very conspicuous, struck him, as well as myself (see figs. 3 a, 3 b, Pl. V). During our voyage along the Norwegian coast I had a good opportunity of taking a series of photographs and sketches of the coast platform at several places. Some of them are reproduced on Pls. V and VI. In a meeting of the Geological Club of Christiania, December 14th, 1893, Prof. BRØGGER delivered a lecture on the subject, and expressed the view that this coast platform was a plane of marine denudation. Dr. H. REUSCH was the first to subject the important morphological feature to a more thorough treatment in his

which it is distinctly separated by a generally steep descent, the slope of which is often as much as 1 in 6, or 10° (cf. Section 24), or even steeper. At other places it may, however, be gentler; in Section 23 it is only 1 in 59, or 58′. The saliences (the shoals) of the submerged parts of the platform are generally covered only by some few metres of water, and its outer, sharply defined edge cannot, as a rule, be considered to be more than 20 metres below sea-level, its depth is probably less. From this edge the coast platform rises very gently inland, as a much dissected, rolling plain; but its upper limit is more difficult to determine and is perhaps often less distinctly defined. It may also differ in different parts of the country. In Nordland we may perhaps put it at 30 or 40 m. above the sea. Dr. H. REUSCH and Dr. ANDR. M. HANSEN assume the upper limit to approach 100 or 120 m. even, the latter putting it between 40 and 120 m. Prof. VOGT says (l. c. p. 41) that it is doubtful whether one ought to put the limit at 40, 50, or even 60 m., but it does not attain a height of 75 or 100 m. in Helgeland.

The slope of the Continental Shelf, outside the steep descent of the coast platform, may be measured either along the highest elevations of the banks between the submarine fjords, or along the bottom of these fjords; but wherever we measure it, we shall find it very gently sloping, indeed scarcely at all, up to the very edge. Section 25 shows a slope at about 100 m. below sea-level, of 1 in 450, or 7·7′, from the highest point of the Halten Bank, to the 300 metres contour-line, this being perhaps the steepest general slope of

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paper, 'Strandfladen, et nyt træk i Norges geografi', *Norges Geologiske Undersøgelse, No. 14, Aarbog for 1892 og 93*, Christiania, 1894. He proves it to be a universal feature of the coast from Lindesnes to North Cape. Prof. J. H. L. VOGT has given a good description of the coast platform of Nordland in his book: 'Søndre Helgeland', *Norges Geologiske Undersøgelse, No. 29*, Christiania, 1900, pp. 35 *et seq.*, 175. See also Dr. ANDR. M. HANSEN, 'Om Strandflaten', *Archiv for Mathematik og Naturvidenskab*, vol. XVII, No. 5 Christiauia, 1894; and *ibid.* 'Menneskeslægtens Ælde', Christiania, 1894—98, pp. 111, 344 *et seq.* Prof. W. M. DAVIS, In his excellent 'Physical Geography', 1899, has also a short description of the coast platform of Norway. He says (p. 368) that it is "sometimes as much as from 3 to 10 miles wide"; but we have seen above that along great stretches of the coast it is much wider. I do not think he is right when he says "that the land stood about 300 feet lower than now, when the platform was cut by the sea"; nor do I believe that "the land stands again in about the same position that it had while the platform was being carved", along those parts of the coast where it is now wanting (*e. g.* east of North Cape, and east of Lindesnes), and that there "the work of making the platform is still going on"; for if so, the platform would now exist near the present sea-level.

this platform. In Section 26 the corresponding slope is 1 in 760 or 4·5′. In Section 23 the slope of the continental shelf is almost zero, whether we measure it along the deepest depressions, or along the saliences. The sections along the bottom of the submarine fjords show, as a rule, either extremely gentle slopes, or none. Section C, along the submarine continuation of the Vest Fjord, gives a slope of 1 in 1917, or 1′ 48″, for the outer part of the fjord, and the other sections give still less.

The Continental Slope is on the whole very gentle in this region between Romsdalen and Lofoten, but especially in its middle portion between 64° 40′ N. Lat. and 66° 40′ N. Lat. The gentlest slope is perhaps in about 65° and 65° 10′ N. Lat. (Sections 24, 25, D) where the great Helgeland Submarine Fjord has probably had its original embouchure. The distance between the 400 metres contour and the 800 metres contour is here about 70 kilometres, giving a slope of 1 in 175, or 19′. It is a striking fact that in this region the continental slope seems to be steeper below the 800 metres contour-line, than between it and 400 m. North and south of this place, the slope is on the whole somewhat steeper. In Section 23, the slope between 401 m. and 818 m. is abont 1 in 84, or 41′, and between 401 m. and 1249 m. it is 1 in 97, or 36′.

A very remarkable feature of this region is seen in the fact that at this place the slope is exceptionally gentle between the soundings of 1249 m. and 1472 m., and it seems as if we here have a comparatively broad plateau — about 60 kilometres broad — extending northward at depths of about 1300 or 1400 m. Unfortunately we have no soundings beyond 900 m. in the sea to the north, until we come to Section C, where we find a similar, but much broader plateau, — 140 kilometres broad, — situated at a depth of between 1260 m. and 1423 m., and separated from the steeper slope of the continental shelf by a depression or suboceanic valley, descending to a depth of 1745 m. and probably opening out to the north. It is probable that this suboceanic plateau extends along the continental slope from 65° N. Lat. to 68° N. Lat. covering a distance of 330 kilometres (180 naut. miles), with a mean breadth of perhaps from 60 to 100 kilometres, and situated at a depth of between 1260 m. and 1400 m. As the probable existence of this, as it seems, considerable plateau was discovered by the soundings made on-

board the *Vøring*, during the Norwegian North Atlantic Expedition in 1876 and 1877; it might be called the *Vøring Plateau*. Whether the same plateau exists in other parts of the Norwegian Sea cannot be determined, owing to the scarcity of the soundings.

In some sections (*e. g.* Nos. 22, 23, D, 24, 26, and even F, and 29) there are perhaps indications of a narrower plateau or terrace at a depth of between 600 m. and 700 m. This terrace seems, according to the contour chart, to be best developed between 64° 50′ and 65° 20′ N. Lat., and between 66° and 66° 20′ N. Lat. Perhaps a similar terrace exists off the western part of the Søndmør continental shelf.

Beyond the 400 metres contour-line, the continental slope between Romsdalen and Lofoten is not incised anywhere by deep and sharply defined depressions resembling river channels or suboceanic fjords. At several places, *e. g.* in 63° 40′ N. Lat. and in 64° 30′ N. Lat. there are, however, embayments which might be small submerged valleys formed by rivers during a previous elevation of the sea-bottom.

The shape of the submarine fjords off the Trondhjem and Nordland coast is very interesting for we there find a very marked tendency to follow the two chief directions mentioned before (cf. p. 45), *viz.* one *longitudinal direction* nearly parallel to the coast and to the longitudinal valleys on land and the mountain axis, and one *transverse direction* more or less vertical to the coast; the latter direction being on the whole less evident than the former. In the interior part of the large submarine fjord off the Trondhjem Fjord and Folden, the arrangement in a longitudinal direction is especially noticeable. There is first a line of deep longitudinal depressions near the coast extending from Hitteren to the mouth of the Folden Fjord. This line is probably continued farther north through the sound inside Vikten, and the submarine channel along the coast off Bindalen, inside Vega, and as far north as the Vefsen Fjord. Another conspicuous line of longitudinal depressions, farther seaward, passes from the deepest depressions off Frøien towards the depressions north of Vikten and off Vega, and probably still farther north. The longitudinal depressions of these two lines are connected by a narrow transverse channel in about 64° 20′ N. Lat. South of the Vest Fjord, there is a splendid longitudinal submarine valley uniting the two

northern submarine fjords, and extending into the Vest Fjord. The deep depressions in the interior part of the Vest Fjord are also splendid examples of longitudinal depressions following the direction of the coast; while the outer part of the submarine continuation of the Vest Fjord is a transverse valley opening out seawards very nearly at right angles to the longitudinal direction. The shape of the small depressions off the mouths of the Ranen Fjord and the Salten Fjord also exhibits perhaps the same tendency towards the longitudinal direction. It is also notewortly that the great depression near the edge of the submarine platform between 65° 18′ N. Lat. and 66° 18′ N. Lat., extends with its narrow northern branch exactly parallel to the longitudinal direction, while its broader eastern branch and the oblong depression east of it (in Lat. 65° 40′ N.) follow a transverse direction nearly at right angles to the coast.

Prof. J. H. L. VOGT has pointed out the existence of a similar system of longitudinal valleys and fjords with narrower transverse valleys and fjords, in Southern Helgeland in Nordland [1]. He states that the longitudinal valleys are on the whole parallel to the strike of the strata and chiefly follow "den leicht erodierbaren, mächtigen Kalksteinlagen", and he is of opinion that this combination of longitudinal and transverse valleys proves that the main features of the present surface relief of the country are due to the erosion of water, and not to glacial erosion.

Dr. H. REUSCH [2] has pointed out that there is a remarkable line of longitudinal valleys parallel to the coast extending from Romsdalen to Nordland; and he ascribes it to the erosion of an ancient river, which, he believed, flowed nearly parallel with the present coast, and entered the sea at Molde in Romsdalen. Prof, W. C. BRØGGER is also of opinion that the longitudinal valleys are the remains of ancient river valleys, which for long distances ran parallel with the coast[3]. It is evident that such a general and im-

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[1] J. H. L. VOGT, 'Søndre Helgeland', *Norges Geologiske Undersøgelse*, No. 29, Christiania 1900, pp. 32—35, and German Summary, p. 164.

[2] HANS REUSCH, 'Nogle Betragtninger over Norges Relief', *Norge i det Nittende Aarhundrede*, Christiania, 1900, vol. 1, p. 54. REUSCH has pointed out a possible similar line of longitudinal valleys in Sogn passing in a north-easterly direction, in *Norges Geologiske Undersøgelse*, No. 35, Aarbog for 1900, Christiania 1901, p. 148.

[3] W. C. BRØGGER, 'Norges Geologi', *Norge i det Nittende Aarhundrede*, 1900, vol. I, p. 22.

portant feature of a considerable part of the Norwegian coast, *viz.* from 62° N. Lat. to 69° N. Lat. or about 950 kilometres (500 nautical miles)[1], cannot simply have been determined by the more incidental directions of the agencies eroding the land surface, but must have a deeper origin; for these agencies, whether running water or moving ice, would naturally have a tendency to work in directions more or less vertical to the coast and to the axis of the mountains as indicated by the transverse valleys, if guided only by by the general slope of the land surface, and certainly not parallet with it. The geological maps of Norway[2] demonstrate clearly a marked tendency in its geological structure towards a north-easterly direction in southern Norway[3], and a more north-north-easterly direction in Nordland. The arrangement in the destribution of the various kinds of rocks, in the Romsdalen and the northern districts, indicate a genetic connection between the above mentioned longitudinal and transverse systems of fjords and valleys, and the geological structure. The longitudinal valleys and fjords of the land surface as well as of the sea-bottom outside, indicate a system of ancient folds and perhaps faults, possibly formed simultaneously with the uplift of the northern Norwegian mountain chain, or the original subsidence of the bottom of the sea basin outside. By this folding, the overlying enormous layers of comparatively weak limestone and mica shists, etc., were carried down along the synclines, to a level with the underlying harder or at any rate, more resisting rocks, Archæan

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[1] Along the west coast of Norway south of 62° N. Lat. another system of longitudinal depressions, with a NNWerly direction, is traceable, cf. the islands of the coast platform off the Bergen coast, and the depressions of the Norwegian channel outside (see later).

[2] 'Geologisk Oversigtskart over det Sydlige Norge' in THEODOR KJERULF, 'Udsigt over det sydlige Norges Geologi', Christiania, 1879. TELLEF DAHL, 'Geologisk Kart over det nordlige Norge', *Norges Geologiske Undersøgelse*, 1891. See also the geological map in W. C. BRØGGER, 'Norges Geologi', *Norge i det Nittende Aarhundrede*, 1900, vol. 1.

[3] *E. g.* the boundary line between the Cambrian-Silurian rocks and the Archæan rocks, passing from Evanger, inside Bergen. to Bæverdalen, Lom, and Vaage. The Sogndal Fjord and the inner part of the Lyster Fjord, etc., follow this direction (cf. REUSCH o. c., *Norges Geologiske Undersøgelse*, No. 35, p. 148). The upper part of the Glommen River, from the Aursund Lake to Tønset and Lille Elvedalen, has a similar direction, and likewise the Bømmel-Hardanger Fjord, etc. The Northwestern boundary line of the Silurian-Devonian rocks of the socalled Christiania district, passing through Sandsver, Eker, Ringerike, and Hadeland, has also a marked north-easterly direction.

rocks, gabbro, granite, serpentine, etc. This mountain folding occurred, as VOGT points out (l. c. p. 7), in Post-Silurian times and was probably of middle or late Palæozoic Age (the Devonian or Devonian Carboniferous Periods). It was at any rate Pre-Jurassic, as the Jurassic formations of Andø did not take part in the mountain folding. During the long space of time that has elapsed since the folding, a denudation of thousands of feet has occured; and most traces of the folds would certainly have been long ago obliterated from the surface relief of the land, or would at any rate not be recognisable to-day, if it had not been for the varying resistance of the rocks to the denudation. The prevailing great features of the present surface relief of the land as well as the continental shelf, have been determined by the greater folds and faults which may often have had a considerable longitudinal extension. The folds and faults may naturally often have been interrupted and disturbed by the eruption of, chiefly simultaneous, igneous rocks, which may often have caused apparent irregularities in the arrangements of the valleys. The denudation of the whole montain system has been considerable. This is proved, as VOGT points out, by the fact that the igneous rocks found at the surface of the present mountain ridges, are all Plutonic and none of them Volcanic or effusive, although the eruptions were evidently to a great extent, simultaneous with the folding, or at any rate not previous to it. This proves also that the folding has penetrated to considerable depths and has probably been connected with extensive displacements of the Earth's crust in this region of the globe. I may point to the fact that many geologists are of the opinion, that the Scotch and the Norwegian mountains belong to the same system. It seems evident, at any rate, that in Scotland we find the same tendency towards a longitudinal direction parallel with the concave curve of the edge of the continental shelf, bounding the deep Norwegian Sea from Scotland to the Lofoten Islands.

I agree with Prof. VOGT that the above mentioned arrangement of broader longitudinal, and generally narrower transverse valleys seems to prove that the main features of the present relief of the land surface of northern Norway, must have owed their prime origin to the erosion of running water, and not to glacial erosion; for a great ice-sheet has necessarily a much greater tendency than running water, to carve valleys along directions radiating from the central region or axis of the land; and would not only have great difficulty in follow-

ing and excavating the longitudinal valleys during its widest extension, but would rather have a tendency to fill them, while it lowered the ridges between them. During the beginning and close of an ice age, the marginal glaciers of the great sheet and the local glaciers, may however, have been more or less able to excavate even the longitudinal valleys, although they would on the whole, naturally have a tendency to change their direction more towards the coast, and this may perhaps actually be seen at some places. That glacial erosion on the one hand has really had a great influence on the surface relief of the land, but has on the other hand not had a predominating influence and has not been the original producer of its main features, seems to be proved by the circumstance, that in Nordland the longitudinal and the transverse directions are not so very prominent in the arrangement of the fjords near the coasts as farther inland, and still less so in the arrangement of the submarine fjords off the coast; the glacial erosion has here been greater than inland. In the outer region there is also less difference in shape between the longitudinal and the transverse fjords; probably because the latter have been more excavated and widened by the glaciers than the former. They were evidently much narrower with steeper sides originally, trough having been carved out by rivers in harder rocks.

One point, which I consider is of much significance is that a system of longitudinal and transverse depressions is also traceable in the arrangement of the submerged fjords and valleys of the Norwegian continental shelf; for if the longitudinal valleys owed their prime origin to the erosion of running water, and not to glacial erosion, this proves, on the one hand, that this area once stood above sea-level; and on the other hand, it throws some light upon the origin of some of the surface forms of the shelf (as I shall mention later on), proving that they are dependent on the structure of the underlying rocks and cannot merely be due to accumulation of loose sediments or glacial drift. Thus perhaps these forms also throw some light upon the formation of the shelf itself.

The depths of incision of the submarine fjords of the Nordland Continental Shelf are strikingly different from those of the fjords of the land inside, although the difference is not nearly so great in this region as, for instance, on the Søndmør-Romsdalen coast (cf. p. 44). The fjords of

Helgeland are on an average incised to a depth of between 1200 and 1500 m. below the highest peaks of the surrounding mountains. The deepest hollows of the Trondhjem-Folden Submarine Fjord are near the coast incised to depths of 300 or 400 m., and in some few cases to nearly 500 m. below the highest parts of the surrounding continental shelf. Farther seawards the incisions are much shallower, and seldom exceed 100 m. below the floor of the shelf. In the submarine fjords to the north, the incisions are, on the whole, not as deep as in this fjord, and seldom exceed 200 m. even in their interior parts, near the coast.

Even the deepest hollows of the submarine fjords of the Nordland Continental Shelf, do not as a rule reach down to such great depths below sea-level as the fjords inside, but they generally seem to approach them, and in this respect differ much from the submarine fjords farther south, *e. g.* off Romsdalen, Søndmør and Sogn. The following table gives the greatest depths of the fjords and the submarine fjords outside in Nordland.

	Greatest Depths in Metres of	
	Fjord	Submarine Fjord outside
Trondhjem Fjord. . .	about 578	between 500 and 520
Folden Fjord	about 500	
Bindal Fjord	725	between 480 and 510
Vefsen Fjord	about 450	
Ranen Fjord	537	478
Sjona	636	
Vest Fjord	650	460 and probably greater
	in its interior narrow part	(outside the mouth of the Salten Fjord is a hollow of 554 m.)

There is, as we see, a striking similarity in the greatest depths of the submarine fjords between Romsdalen and Lofoten; they all approach 500 m., which is somewhat less than the average greatest depths of the fjords of the coast inside. As mentioned on p. 48, it seems probable that this depth may approximately indicate the base-level of erosion during some previous and comparatively recent period of elevation of the land.

It is an interesting fact, in this connection, that at the edge of the continental shelf there are no embayments (cf. p. 54) allowing us to trace with certainty any of these great submarine fjords down along the Continental Slope to depths exceeding 500 m. There are many irregularities and undulations in the shape of the isobaths of 600, 700, and 800 m. which may indicate ancient valleys; but if so, they are now so much obliterated as to be hardly recognizable. How it is at greater depths we cannot tell, as the regular soundings do not go beyond 800 m.; and even this contour cannot be drawn with sufficient minuteness of detail.

d) THE NORWEGIAN COAST SOUTH OF 62° N. Lat., AND THE NORWEGIAN SUBMARINE CHANNEL.

A striking and very remarkable feature of the morphology of the Norwegian coast is, that the broad *continental shelf*, so conspicuous in its northern parts, seems suddenly to disappear south of 62° N. Lat., or south of the entrance to the Nord Fjord, and does not occur to any prominent extent along the whole of the coast between this place and the Christiania Fjord. The *coasl platform* is also much narrower and even partly absent in this region. Instead of a submerged shelf the coast is along the whole of this distance bounded by the deep and long submerged depression or fjord, called the *Norwegian Submarine Channel*. It is a noteworthy fact that the partial or total absence of a continental shelf, as well as a reduction of the coast platform, coincides exactly with the extension of this channel. It is, however, doubtful whether it is quite correct to say that southern Norway has no continental shelf, as the great platform of the North Sea might be considered as its original continental shelf, in which the Norwegian Channel forms an incision, just as in the case of the submarine fjords of the shelf farther north, only that this fjord is so very much greater and follows the coast.

At many places, or perhaps even at most places, the sea-bottom slopes more or less abruptly from the coast towards the bottom of the Norwegian Channel without forming any terraces; but at other places distinct indications of platforms or shelves, at least in one and often in two levels, are traceable, and are sometimes even well developed (cf. Sections 35—41). The upper level is situated very nearly at the present sea-level (cf. Sections 35, 38—42),

and descends as a rule, only to some few metres below it. This level is indicated by the shoals and skerries bordering the coast, and it corresponds evidently to that of the coast platform farther north. This coast platform is comparatively well developed along the west coast although it is, on the whole, much narrower than in Nordland. Farther south, along the south-west coast, it is still narrower, and less continuous. East af Lindesnes the coast platform is imperfectly developed, but is distinctly traceable at several places, *e. g.* Section 40 and 41. In several sections, *e. g.* Nos. 37 and 38, there are indications of a somewhat lower, but distinct terrace at depths between 30 and 50 m. It may be difficult to say whether this level ought to be referred to the present coast platform or to the continental shelf. The terrace, at depths between 70 and 110 m., seen in Sections 35, 36, 40, and perhaps in 41, is evidently to be referred to the continental shelf. In Section 41, there is also a terrace at between 212 and 222 m.

The *Norwegian Submarine Channel* exhibits exactly the same general features as the Norwegian submarine fjords farther north, only on a much larger scale. Its total length is about 890 kilometres (480 nautic. miles) from its inner end, off the mouth of the Christiania Fjord, to its embouchure at the edge of the continental shelf west of Søndmør. The average width of the channel is about 104 kilometres (56 nautic. miles) in its outer and shallowest half, north of Stavanger or the Bukken Fjord. In its inner half the average width is about 74 kilometres (40 nautic. miles). Its narrowest part is at the south point of Norway, where the width is about 61 kilometres. The greatest depths of the channel are found near its inner end, and are greater than those of other Norwegian submarine fjords. There is a deep hollow, 85 kilometres long, with depths greater than 600 m.; its greatest known depth is exactly 700 m. In another isolated small hollow, off Christianssand, the depths also exceed 600 m. (630 m.). Just off Lindesnes there is an isolated hole with a depth of 677 m. (see Section G, Pl. . . .), if the sounding be correct. In an area, 160 kilometres long, of the inner part of the channel the depth exceeds 500 m. The other half of the channel is much shallower, and exhibits the regular threshold or barrier of the submarine fjords, having very nearly the regular depth (see p. 49). Along a distance of 210 kilometres (115 nautic. miles) off the Bukken and Bømmel Fjords the depths are less than 300 m., except in some few isolated hollows, and at its shallowest place

off Utsire, the channel is only 273 m. deep. From this place the surface of the barrier slopes on the whole very regularly and extremely gently, both inwards towards the deeper part of the channel, and outwards towards the edge of the continental shelf, where it is almost horizontal, the slope being 1 in 2690, or 1′ 17″. The channel is 404 m. deep at its mouth on the edge of the shelf which seems to be very sharply defined (see Section G). In its outer half the Norwegian Channel forms a very shallow depression in the general floor of the North Sea (see Sections 35—37), the incision being only 140 or 150 m. below the general level, off Utsire. In the region off the Sogne Fjord there is an indication of two parallel depressions along the bottom of the channel, one deeper longitudinal valley, with several hollows, near the outer coast-line, following the trend of the coast, and with the deepest hollow (471 m.), of the outer part of the channel, situated just off the mouth of the Sogne Fjord. This submarine valley may be traced southward to the mouth of *Selbjørn Fjord* in about 60° N. Lat. Another shallower depression passes southward near the western side-slope of the channel. The bottom of this depression is more regular and with no isolated deeper hollows, it seems to form the direct continuation of the deepest part of the barrier farther south. It seems to me to be possible that these two comparatively shallow submarine depressions are remnants of longitudinal valleys or fold-valleys, which have now been filled up to a great extent. They run exactly parallel to the fold, which is evidently indicated by the long row of islands and skerries extending in a line southward from *Utvær* Lighthouse — just north of the mouth of the Sogne Fjord — over Feie, Alvø, Store Sartr (or Sotrø), and Hufterø to *Selbjørn Fjord*, or exactly as far south as the eastern longitudinal valley (see above). If this assumption be correct, it proves that even some details in the present form of the bottom of the Norwegian Channel owe their prime origin to the tectonic structure of the underlying rock; and this makes it again probable, as before pointed out, that these valleys were, to some extent at least, first formed by the erosion of running water on a dry land-surface, because the glacial erosion was hardly sufficiently dependant on the tectonic structure of the underlying ground to form parallel valleys such as these.

In accordance with several previous authors I consider it probable that the Norwegian Channel was once part of the bed of an ancient river, the

Baltic River, draining the Baltic basin, as well as south-western Sweden and southern Norway. This was probably at the same period when the ancient Barents River, through the Barents Channel (see p. 26), drained the extensive basin to the northeast surrounding the present Barents Sea. The Norwegian Submerged Channel bears, in my opinion, much resemblance to the submerged White Sea and Murman Channel, near the northern extremity of Norway. The prime origin of both these channels has probably been great geological dislocations of some kind at some remote period[1]; but their present form and outline are due, according to my view, to atmospheric erosion (*i. e.* first river erosion, and later glacial erosion) and subsequent partial filling up with glacial drift. It may be objected that the inner end of the Norwegian Channel is too broad and too abrupt to be an original river-channel; but on the one hand, the rivers from at least three extensive drainage-areas the Langesund Fjord, the Christiania Fjord, and the Gottenburg-river have converged towards this very place, and in fact in the slopes descending towards the floor of the Norwegian Channel, we may still find traces of the former channels of these rivers. During a previous period the Baltic River drained the same way. On the other hand, it is very probable that just in this part of the sea much glacial drift has been deposited on the sea-bottom, and has to some extent filled up the end of the channel and made it more abrupt, and has partly obliterated the original valleys. It is probable that the Danish Belts and Kattegat have been filled up, and the entrance to the Christiania Fjord and the sea outside it, for instance, has also to a great extent been filled up. At several places in the interior of this fjord, we have depths of up to 400 m., and the bottom of the river-channel descending gradually from these depths to the floor of The Norwegian Channel would have had no abrupt slope, even if The Norwegian Channel at that time had the same depth as it has now, which, however, is hardly probable, as it may afterwards have been much excavated by glaciers.

Prof. AMUND HELLAND is of the opinion that the Norwegian Submarine Channel was chiefly formed by erosion of the Scandinavian glacier which

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[1] Prof. W. C. BRØGGER has pointet out that the Kristianiafjord and its continuation in Skagerak was originally formed by faults or by a depression of the Earth's crust (*Nyt Mag. for Naturvid.*, vol. XXX, Christiania, 1886, p. 231). It is of interest that W. RAMSAY has proved that the Gulf of Finland is also an area of dislocations.

during the Great Ice Age was deflected by the ice-masses, situated to the south, and was compelled to follow this direction along the Norwegian coast. His view seems also to be that the channel has become deepest in its inner part, in Skagerak, chiefly because the erosion of the glacier was most active in this region where its volume was greatest but its width narrowest[1]. The deep Skagerak depression would thus be a real rock basin, carved in solid rock. Although I admit that the original river channel has probably been much deepened and widened by the erosion of the enormous glacier passing through it, and although this glacial erosion has chiefly given the channel its present shape and outlines, and its final effect may have been greatest in the inner part, still I consider it probable that the chief reason why the channel is so much deeper in the Skagerak is not the difference in the glacial erosion, but that the outer part of the channel has to a great extent been filled up with glacial drift, in a manner similar I believe, to that in wich the channel outside the White Sea has been filled up. The glacial motion of vast areas has evidently converged to form the huge glaciers filling these channels (the White Sea and the Norwegian Channel), and comparatively large quantities of drift have been carried along them, and must have been deposited outside the edge of the glaciers, probably in the sea. During the widest extension of the great ice-sheet, the channels were probably completely filled by their glaciers, and the glacial drift would then chiefly be deposited in the deep sea outside their entrances. It is, for instance, possible that the apparent elevation of the sea-bottom which seems to extend some distance north outside the entrance to the Norwegian Channel, off Søndmør, has been formed in this manner. But if, after the retreat of the glacial margin, a long stationary period occurred, during wich the terminal edge of the glacier was situated, for instance, off the coast somewhere between the Sogne Fjord and the Bømmel Fjord (and somewhere outside the entrance to the White Sea), then the glacial drift would necessarily be deposited in the outer part of the channel, outside the glacial edge; enormous quantities of drift would gradually be accumulated there, forming barriers; and the sea outside would simultaneously be silted up by deposition of glacial detritus; while naturally no waste was deposited on the bottom of the channel inside, covered by the

[1] AMUND HELLAND, 'Om Jæderens løse Afleiringer', *Meddelelser fra den naturhistoriske Forening*, Christiania, 1885, p. 41.

great and active glacier; on the contrary all loose matter existing there before the glaciers, was gradually carried out to their terminal margin. The accumulation of the glacial drift outside the glacial edge, would however, gradually increase the resistance of the glacier, and the edge would have to retreat slowly as more drift was deposited in front of it. The glacial edge may also for other reasons (*e. g.* climatic changes) have had to retreat more or less slowly during a long period, and thus the outer part of the channels have become filled up with glacial drift for some long distance. But if, after this, a period of much more rapid retreat had followed, the inner parts of the Norwegian channel and the White Sea would have been comparatively little filled up, until the retreat was again stopped during a new stationary period, *e. g.* at the inner end of the Norwegian Channel.

From another point of view it seems also to be clear that the barrier of the outer part of the Norwegian Channel is not exclusively a rock barrier formed by the greater glacial excavation of the inner basin; it must to a great extent have been formed by glacial drift.

If we assume with Helland, that the inner deep basin has to a great extent been carved by glacial erosion, we must also assume that the glacial drift thus arising, has been again deposited outside the terminal edge of the glacier, near the entrance to the channel and in its outer part. And if the erosion in the inner part has been considerable, the volume of the barrier formed by the drift in its outer part must naturally be equally great. It therefore seems to be impossible that the barrier is not to a very great extent formed by glacial drift.

Let us assume that before the Ice-Age, the mean depth of the Norwegian Channel was about 500 m., and that its outer part along a distance of 650 kilometres, has been filled up to an average depth of 320 m., *i. e.* with a barrier averaging 180 m. in thickness[1]: let us farther assume that the aver-

[1] As before stated, the channel is, at its shallowest place 273 m. deep; this would make a moraine 227 m. high above the depth of 500 m., which certainly is no formidable height. The moraine at Svelvik, across the Drammen Fjord is 190 m. high from base to summit, and the glacier which formed it came, from a very limited area, and was comparatively insignificant as has been proved by BRØGGER. See W. C. BRØGGER, 'Om de senglaciale og postglaciale Nivåforandringer i Kristianiafeltet', *Norges Geologiske Undersøgelse*, No. 31, Christiania, 1900, p. 138.

age breadth of the channel was 80 kilometres. We then find the volume of the entire mass of drift to be about 9360 cubic kilometres.

The drift-masses now filling the Norwegian Channel may also of course, to some extent, have been carried into the sea during the late glacial period by the more local glaciers of the fjords of western Norway. The Bukken Fjord, for instance, — off the mouth of which there is a ridge with depths of less than 250 m. (see map, Pl. XI) — and perhaps also the Hardanger-Bømmel Fjord may have been filled by glaciers, which at some time reached the side slope of the Norwegian Channel and there deposited their detritus[1]. But I do not believe that the masses carried in this manner have been of great importance compared with those carried by the great glacier of the Norwegian Channel, and they have only formed the uppermost layers of the barrier. That considerable layers of glacial drift actually have been accumulated in the region of the barrier across the Norwegian Channel, is directly proved by the borings of Mr. TELLEF DAHLL on Jæderen in 1874. The thickness of the drift or till near the shore, was then found to be 124 m. (395 Norwegian feet), and the total thickness of the drift layers is probably much more; HELLAND estimates them to be at least 150 m.[2]. As pointed out by HELLAND, these layers consist to a great extent of matter which has evidently been carried a long distance from the east, probably by the great glacier of the Norwegian Channel. There is, for instance, a great quantity of stones (boulders) which must have originated from the region round the Christiania Fjord. If the glacial drift could attain such a thickness on land, on the side of the channel, and near the inner end of its barrier, we may certainly expect that it has attained a greater thickness in the deep channel itself. For it is probable that a glacier filling a broad and deep channel, such as this, would carry much more drift along the middle of the channel than on its shallower sides; in the middle the glacier being composed of ice originating from a much more extensive area, was much thicker and had a more violent motion.

The White Sea is 302 m. at the deepest, and the Vardø channel is 417 m. and at one place 460 m. Let us assume that the channel along the

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[1] W. C. BRØGGER is of this opinion, cf. *l. c.*, p. 109.

[2] AMUND HELLAND, 'Om Jæderens löse Afleiringer', *Meddel. fra den naturhist. Forening*, Christiania, 1885, p. 28.

Murman coast was originally something between these depths, or about 360 m. The sea near the entrance to the White Sea is between 67 and 60 metres at its deepest: this makes a moraine about 300 m. high. We know nothing as to the original shape of the submarine channel uniting the White Sea with the ocean outside, but let us assume that its average width was 30 kilometres, and that it has been filled up along a distance of 600 kilometres with a layer having a mean thickness of 200 m. We then find that the entire volume of drift now filling the channel, would be something like 3600 cubic kilometres.

Although the above calculations naturally are very uncertain, they may give some approximate idea of the quantities of transported matter. Prof. AMUND HELLAND[1] has estimated the distribution in Germany and Russia, of the glacial drift originating from Sweden and Finland, to be about 2,040,000 square kilometres, and its mean thickness to be 30 m. (100 feet), which if anything is too little. The entire volume of the northern drift covering this area would thus be about 61,300 cubic kilometres. The figures obtained by our calculations above are small when compared with this quantity, which, however, is much too little. We have seen above, that the Quaternary layers on Jæderen, chiefly consisting of glacial drift, were at one place 124 m. thick, and that their total thickness is probably 150 m. The Quaternary layers, chiefly glacial drift, covering Zealand was at one place found by boring to be 126 m. thick; at many places in Germany and Holland the borings have given even much greater thicknesses; *e. g.* at Blankenese, near Hamburg, they bored to 192·6 m.; at Amsterdam to 171 m., and at Strassburg in the Uckermarck to 204 m. even, without reaching the bottom of the Quaternary layers[2]. These quantities of drift have been transported by ice-sheets that had a radial motion extending over comparatively flat regions; and such ice sheets could certainly not carry nearly as much moraine matter, as could glaciers confined within comparatively narrow channels and formed of ice-masses converging from an extensive area, such as must have been the case with the glaciers once passing through the Norwegian Channel and the White Sea Channel.

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[1] AMUND HELLAND, 'Ueber die glacialen Bildungen der nordeuropäischen Ebene'. *Zeitschrift der Deutschen Geolog. Gesellschaft*, 1875, p. 95.

[2] Cf. FELIX WAHNSCHAFFE, 'Die Ursachen der Oberflächengestaltung des Norddeutschen Flachlandes', 2nd edition, Stuttgart, 1901, p. 66.

In fact, we cannot expect it to have been otherwise, as the large quantities of drift transported by these enormous glaciers must have been deposited somewhere; and if not in the sea outside the channels, we have to look for it in the outer parts of the channels themselves. It ought, for instance, to be remembered that whilst the drift from Sweden and Finland was chiefly carried out over the German and Russian low-lands, the drift from southern Norway and southwestern Sweden was evidently to a great extent, during the late glacial period, carried westward through the Norwegian Channel and the North Sea, and must have been deposited somewhere in that region. During the widest extension of the ice-sheets, glacial drift was carried from Scandinavia across the North Sea to England, and at the same time was probably deposited to a great extent, on the platform of the North Sea.

e) THE PLATFORM OF THE NORTH SEA.

The platform of the North Sea is evidently much the same formation as the Norwegian continental shelf; but it is much more level, and has very few indications of submarine fjords; Sections 35, 36, and 43 give a good idea of its levelness. The surface slopes extremely gently from the German and Dutch coast, towards the edge of the platform between the Shetland Islands and Søndmør, the average being about 2 in 8000, or 26″. But as seen in Section 43, from its edge to Holland, there are indications of several different levels. On the continental slope outside the edge of the platform, there is a distinct shelf at between 384 and 439 m. or very nearly at the same level as the bottom of the outer part of the Norwegian Channel and other submarine fjords. The edge of the great platform is situated at about 217 m. below sea-level, and its surface rises slowly southward until there is a more abrupt ascent from 155 m. to 130 m. Then there is again a more even level of between 130 and 115 m. below sea-level, extending southward, until again a more sudden ascent of from 116 m. to 80 m. South of this place the level varies between 80 m. and 66 m., until there is perhaps a last steeper ascent from 66 m. to a higher level of between 30 m. and 50 m. nearest the coasts. On the platform of the North Sea we may thus probably distinguish the following five levels:

1) a level outside the edge of the platform, at depths between 384 m. and 439 m., corresponding to the outer base-level of the submarine fjords.
2) a level near the edge of the platform with depths between 155 and 217 m.
3) a level with depths between 115 and 130 m.
4) a level with depths between 66 and 80 m.
5) a perhaps more doubtful level with depths between 30 and 50 m.

VI. THE CONTINENTAL SHELF AND THE SUBMARINE FJORDS OF THE FÆROES AND ICELAND.

As the plateaus of the Færoes and Iceland, to a very great extent, date it would seem, from a recent geological age, at least so far as their upper now exposed parts are concerned, a careful comparison of their continental shelves, with those of Norway, western Europe, and other northern lands, might give information of importance for the history of the continental shelves in general. Though their shelves are separated from that of western Europe by the deep Færoe-Shetland Channel and the shallower strait between the Færoes and Iceland, yet they are nevertheless to some extent connected with it by the Wyville Thomson Ridge and the Færoe-Iceland Ridge, situated at levels of between 380 m. and 580 m.

THE FÆROE ISLANDS.

The Færoes (Pl. XXIII) are surrounded by a well developed continental shelf, from 42 to 80 kilometres, or at some places even 100 kilometres, broad. The Færoe Bank, to the south-west of the islands, is situated about the same level as this shelf, and is evidently part of the same formation; but it is separated from the shelf by a somewhat deeper (290—380 m.) submarine sound. The chart No. 55, published by the *Kongelige Søkort-Arkiv* of Copenhagen, Edition 1902, gives a fairly good idea of the Færoe Continental Shelf. By the kindness of Commodore G. Holm, Director of the *Søkort-*

Arkiv[1], I have also had an opportunity of studying the many thousand soundings and the excellent, still unpublished charts made in these waters by the Danish Government Survey. Last summer (1902) a great many soundings were also taken along the edges of the Færoe Continental Shelf by the Norwegian Government steamer Michael Sars, and have liberally been placed at my disposal by Dr. Hjort, the leader of the expedition. I have used both the Danish and the Norwegian soundings, as well as those of the English Admiralty Chart No. 2, for the construction of the bathymetrical chart (Pl. XXIII). As the numerous regular Danish soundings do not descend much beyond 100 fathoms or 180 m., they give a very perfect description of the surface relief of the upper level of the continental shelf, but give only little information of the situation of the edge of the shelf and no information at all, of the continental slope round these interesting islands. In this respect the Norwegian soundings from the Michael Sars are very valuable, as they are to a great extent taken in deeper waters near the edge of the shelf and on the continental slope.

Coast Platform. A very remarkable feature is the apparent absence round the islands, of a coast platform similar to that of Norway. In spite of the very active marine denudation to which the comparatively weak basaltic rocks of the islands are at present subject, their precipitous coasts descend very often abruptly into the sea, down to depths of 50 or 60 m. and even 70 or 80 m., and have no girdle of skerries or shoals outside them, with only at some places, a very narrow ledge of rocks constantly washed by the surf, which can hardly be considered as more than a well developed shore-line. One can, as a rule, sail with a ship very near the precipitous walls of the coast. Considering the rapid effect of the present wave action on the islands, which is, for instance, much greater than that on the Norwegian coast which is built up of hard Archæan rocks, it may seem difficult to explain this almost total absence of a coast platform.

The Continental Shelf is, on the whole, very level, and slopes gently and fairly regularly seawards from the foot of the coast rocks. The 100

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[1] I take this opportunity of offering Commodore G. Holm my best thanks for the valuable assistance he has rendered me in several ways during my work.

metres contour surrounds the islands at an average distance of about 12 kilometres; and the greater part of the shelf seems to be situated at depths between 100 m. and 170 m. The general slope of the shelf is between 1 in 500, or 7′, and 1 in 1000, or 3·5′ (cf. Sections 44, 46), On the west and north side, the shelf has a tendency to be shallower than on the eastern and especially on the south-eastern, side of the islands (cf. Section 44). The edge of the shelf is not, as a rule, very sharply defined; and its situation and depth below sea-level is often difficult to determine owing to the fewness of the soundings. The continental slope outside the edge is also, as a rule, comparatively gentle. It seems as if the edge, lies to a great extent at depths between 160 m. and 188 m. To judge from Section 44, it seems to be at about 233 m. on the south-eastern side of the islands, but on the Færoe Bank the level is again higher. It is noteworthy that the top of this bank is situated at a depth of 90 m., a level which is rather prominent on the west and north side of the islands, where several banks (*e. g. Mylings-Grind, Fuglefjords-Øje*) are at exactly the same depth (cf. Pl. XXIII, and Sections 44, 46).

The Submarine Fjords of the Færoe platform are not numerous and are generally not very deep. The greatest depths of the fjords and sounds between the islands, do not exceed 188 m. The deepest known hollow is in the sound between Kalsö and Österö, with depths between 160 m. and 188 m. This long hollow is separated from the deeper sea to the north by a barrier or plateau at 80 m. below sea-level. Between Kalsö and Kunö there is a similar long narrow hollow 132 m. deep; between Strömö and Vaagö there is a hollow 134 m. deep. Between several other pairs of islands there are also hollows, which, however, are only from 105 m. to 128 m. deep; they are all separated from the deeper sea outside by barriers or plateaus with depths of 65 to 80 m. below sea-level.

One of the deepest and best developed submarine fjords of the Færoe Continental Shelf is perhaps, a comparatively long and narrow channel between Sandö-Bank and Syderö-Bank on the south-east coast (see Pl. XXIII. the 300 m. contour), in which there are soundings of 300 m. and 350 m, To what depth this, or any other submarine fjord descends, one cannot say, but it seems as if it is a tributary to the Færoe-Shetland Channel.

In a submarine fjord on the west side of the sound between Syderö and Sandö, there is a submarine fjord in which the deepest sounding is 301 m. (Pl. XXIII). I have mentioned before that the channel between the Færoe-Bank and the Færoe platform is about 300 m. deep.

The Continental Slope of the Færoe platform is as before mentioned gentle, varying, as a rule, between 1 in 45, or 1° 16′, and 1 in 60, or 57′: it does not seem to be very regular, and only at a few places does it descend in one sweep from the edge of the platform, to the deep regions of the ocean north and south. It is evidently steepest to the north or north-northeast from the islands (see Pl. I and XXIII), where it descends from 280 m. to 1783 m. at an average inclination of 1 in 19, or 3°; and a little farther east from 440 m. 2222 m. at an average slope of 1 in 36, or 1° 36′. A little more due north from the islands, the continental slope is evidently interrupted by a *suboceanic terrace* at a level of between 1105 m. and 1275 m. (cf. Section 44). A very similar *suboceanic terrace* or *shelf* with soundings from 1177 m. to 1215 and 1356 m., seems to exist west of the Færoe-Bank and south of the Færoe-Iceland Ridge (see Pls. I and XXIII); and also perhaps between the Færoe-Bank and the Rockall Bank where there are soundings of 1134 m. and 1189 m. The slope from the Færoe platform towards the bottom of the Færoe-Shetland Channel seems to be very irregular and is, perhaps, much intersected by submarine valleys. To the north-east of the Færoes an isolated sounding of 373 m. was taken in 1876 by the Norwegian North-Atlantic Expedition, in 63° 1′ N. Lat. and 3° 58′ W. Long[1]. But as the expedition on board the Michael Sars sought in vain for this bank in 1902, and as no more soundings reaching the bottom have been taken in this region, nothing can be said as to its shape and extension. About 44 to 54 kilometres nearer the islands several soundings of 614 m., 629 m., and 651 m. were taken from the Michael Sars (Pl. XXIII).

[1] H. Mohn, 'The North Ocean', *The Norwegian North-Atlantic Expedition 1876–1878*, Christiania 1887, p. 45 and Pl. I.

The Fœroe-Shetland Channel or the Lightening Channel.

As far as we know this channel now (Pl. XXIII), it much resembles a great river valley and it probably receives many smaller tributaries from both sides. Owing to the fewness of the soundings, especially on the Færoe side, the details of these tributaries cannot, however, be traced out. The bottom of the channel (see Section H) seems to be for a considerable distance — from between the Færoes and Shetland to its inner end — at a very uniform level of about 1170 m. and 1189 m. In an area in about 60° 35′ N. Lat. there is for a long distance only one deep sounding of 1024 m. but more soundings might probably give greater depths, and the shape of the channel northwards from this area cannot be exactly determined: the shape of the isobaths in Pl. XXIII is consequently very hypothetical[1]. Farther north, evidently near the mouth of the channel, the depth increases to 1262 m. These depths are strikingly uniform and bear much resemblance to those of the above mentioned (p. 73) suboceanic plains off the north side and the south-west side of the Færoes. It may not seem improbable that they indicate a base-level of erosion during a period when the sea-bottom stood so much higher.

By the narrow Wyville Thomson Ridge the Færoe-Shetland Channel is separated from a short channel or submarine valley (north of the Hebrides), with depths of between 1015 m. and 1088 m., which probably opens out on to a suboceanic plain to the south of the ridge, with soundings of 1042 m., 1256 m., 1289 m., and 1326 m. This plain evidently corresponds to the above mentioned plains at similar levels. The comparatively broad and deep sea between the Rockall Bank and the British Isles, with depths of 2319 m. and more, can hardly be considered as a continuation of the above mentioned narrow and well defined channel.

The Wyville Thomson Ridge has a very peculiar surface sculpturing, which decidedly resembles that of a mountain ridge eroded by atmospheric

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[1] In 61° 3′ N. Lat. and 4° E. Long. a sounding of 479 was taken from the Michael Sars in 1902; but as the lead was lost, this sounding is very doubtful.

agencies[1]. Its slopes, on both sides, seem to be furrowed by valleys resembling river valleys. Its highest peaks stand about 800 m. above the floor of the channels on both sides, and at 320 m. and 384 m. below present sea-level (see Section 45). To judge from the charts, the deepest pass across the ridge seems to be about 576 m. below sea-level, but more soundings might possibly give other depths. The slope on both sides of the ridge seems to be comparatively steep at some places.

ICELAND.

Iceland is on all sides surrounded by án often sharpely defined continental shelf[2], very similar to that of the Færoes. It is, as a rule, from 60 to 80 or 100 kilometres broad, and only on the south coast narrows to a breadth of 15 or 20 kilometres off Eyafjalla Jökull and Myrdalls Jökull. The shelf is much intersected by shallow submarine fjords and valleys. The level of the higher ridges or banks of the shelf between these fjords is, to a great extent, near 100 m. below sea-level.

Coast Platform. On Iceland we find also a striking absence of a typical coast platform, near present sea-level, although perhaps not to the same extent as in the case of the Færoes, already mentioned.

Off *Reykjanes* a row of skerries and shoals, *Fugla Sker*, etc., extend towards the south-west, right up to the very edge of the continental shelf where *Blinde Fugla Sker* are situated. Off *Vestmanna Eyar* there are many skerries, and the *Geirfugla Sker* is situated near the edge of the shelf.

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[1] Prof. J. W. SPENCER has with some short happy remarks pointed out the land-like forms of the Shetland-Færoe-Iceland Ridge, etc., in *Geol. Mag.*, Dec. IV, vol. V, London, 1898, p. 36 (see also *ibid.* vol. VI, 1899, p. 561); but having evidently not had the more detailed charts at his disposal, his depths are somewhat inaccurate. The *col* of the Wyville Thomson Ridge is, for instance, not submerged 3 000 feet. See also W. H. HUDLESTON, *Geol. Mag.*, Dec. IV, vol. VI, 1899, pp. 145 *et seq.*

[2] For my study of the Icelandic continental shelf I have used the following charts published by the Kongelige Søkort-Arkiv, Copenhagen: Nos. 55 (Iceland and the Færoes, Edition 1902), 114 (Iceland, Edition 1902), 189 (east coast, 1901), 190, 191, 192, 193, 194, and 202. Through Commodore G. Holm's kindness I have also had an opportunity of studying the still unpublished chart of the region north of Huna Floi, Skaga Fjord and Eya Fjord, with thousands of new soundings.

Similar formations also exist outside other parts of the Icelandic coast, *e. g.* at *Papey* on the south-east coast; off *Tjörnes* on the north coast; in the inner part of the *Breidi Fjord,* etc. Some of these platforms, with skerries and shoals, are evidently situated in regions where comparatively recent volcanic eruptions have occurred, *e. g.* off the *Reykjanes Peninsula,* and it is possible that they may have been formed by submarine lava streams. But, it seems probable at least at some places, that the upper surface of their skerries and shoals has actually been levelled by marine denudation. There is, however, a striking difference between these small platforms and the broad continuous coast platform of Norway. If these Icelandic formations actually are parts of an identical coast platform it seems difficult to understand why traces of it only occur at some few and comparatively isolated places, while the rocks along the greater extent of the coast apparently descend in one sweep, more or less abruptly, down to the level of the inner part of the continental shelf. The descent of the coastal rocks is, on the whole, not so steep and does not become so deep near the coast as in the case of the Færoes. It is, however probable that the sea near the coast of Iceland has been more silted up by waste.

Along the coasts, on the present land surface of Iceland, there are, as far as I have seen it, no platforms or plains perfectly similar to the present Norwegian coast platform. Along the south coast there are, for instance, extensive low-lands, in front of the high and boldly ascending mountains, Eyafjalla Jökull, Myrdals Jökull, Öræfa Jökull, etc.; but they are modern marine and alluvial plains,[1] and I have not been able to find out from the descriptions whether they may possible cover a coast platform and whether rocks *in situ* project on their surface in a similar manner as in the case of Jæderen in Norway, for instance. At other places there are also low plains near the coasts, which may, however, be the natural surface of old lava streams; this seemed, for instance, to be the case at Reykjanes, to judge from a short visit of a few hours, I paid there in 1882. Dr. Th. Thoroddsen mentions the very interesting lowland, *Myrar,* at the bottom of the Faxa Fjord on

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[1] Th. Thoroddsen, 'Postglaciale marine Afleiringer, Kystterasser og Strandlinjer i Island', *Geografisk Tidsskrift,* vol. 10, Copenhagen, 1890, pp. 211 *et seq.*

the west coast[1]. This plain has an average height of only 20 or 30 m. above sea-level, and is bounded by steep mountains arranged in a semicircle round it, 50 or 60 kilometres from the present coast. Several evidently eroded, valleys extend from the plain in between these mountains. The plain is much covered by bogs and moors, with numerous low, ice-worn and striated ridges of basalt projecting in between. The plain was submerged below sea-level during the end of the Ice Age, as is proved by layers of clay with arctic moluscs, occurring many kilometres inside the present shore-line. Thoroddsen points out the great resemblance between the inner part of the Faxa Fjord and that of the Breidi Fjord, only that the plateau of the latter is a little more submerged. If the sea-level in the Faxa Fjord were raised 40 or 50 m. the lowland, *Myrar*, would be submerged; and, just as in the case of the present Breidi Fjord, the inner part of the fjord would be filled with a multitude of islands and skerries, the numerous basaltic ridges. If, on the other hand, the bottom of the inner part of the Breidi Fjord were to be raised 30 or 50 m. it would be transformed into a boggy plain with numerous basaltic ridges. Thoroddsen is evidently of the opinion that both these plains or lowlands are basaltic plateaus which have been lowered to their present level by troughfaults; but it might still seem doubtful whether their present plane has not, to some extent at least, been formed by marine denudation (cf. later Chapt. IX). With regard to this point, it seems to be of some importance that, as far as I can make out from Thoroddsens description, the bottom of the "eroded valleys" extending from the plain of Myrar in between the mountains, is at about the same level as this plain and is in fact a direct continuation of it.

Continental Shelf. The general floor of the *continental shelf*, between the submarine fjords, lies at a fairly uniform depth round the whole island, sloping gently from the coast towards the edge of the shelf. As regards depths and slope this shelf seems to much resemble that of the Færoes. It may however, be, that on Iceland as well as on the Færoes, we find indications of the same law, which we possibly found in Norway; *viz.* that the general floor and the edge of the shelf stand at the highest level at that point

[1] *Geografisk Tidsskrift*, vol. 16, Copenhagen, 1901, p. 60.

at which the land inside is highest, and the shelf itself narrowest[1]. Iceland is highest along its south coast, where the continental shelf also is very narrow, and lies comparatively high. Off *Öræfa Jökull*, the highest mountain on Iceland (1920 m. high), the shelf is from 40 to 50 kilometres broad; its general floor is situated from 80 to 110 m. deep, and its edge about 115 m. Off *Borgarhöfn* and *Papos* (Section 47, 48) east of Öræfa Jökull, the shelf is about 64 kilometres broad, whilst its level is much the same, with a sharply defined edge at 94 and 111 m. Off *Eyafjalla Jökull* and *Myrdals Jökull* the shelf is only 14 or 15 kilometres broad, and its general floor perhaps still higher. But even in other regions where the land is not so high and the continental shelf not so narrow *e. g.* off *Dyra Fjord* (Sect. 52) where its breadth is 82 kilometres, and off the northwest corner of the island (Sect. 54) where the breadth is 73 kilometres it lies at similar depths. The section 55 northward, along the ridge between *Huna-Floi* and the *Skaga Fjord* gives very similar depths, although the floor of the shelf is here less even. The section northeastward from *Vidvikrheidi* (Sect. 57) along the ridge between the Bakka-Floi Deep and the Hjerads-Floi Deep, where the breadth of the shelf is 85 kilometres, gives a fairly horizontal level of between 100 and 120 m. below the sea-surface, with more isolated elevations rising to about 90 m. below sea-level. On the whole, it may perhaps be said, that, where the sections are most regular, the floor of the continental shelf exhibits a tendency to approach a level of about 100 m. below the sea-surface (cf. Sections 47, 48, 49, 54, 57). In some regions off the east and north-east coast of Iceland, *e. g.* Sections 56, 58, and 59, the level of the submerged shelf is somewhat deeper, at depths varying between 100 and 200 m., whilst its edge lies between 170 and 200 m. below sea-level. In Section 58, for instance, the floor of the shelf slopes very regularly from a depth of 47 m. near the coast, to the edge of the shelf at 185 m. below sea-level. In Section 59 the edge is evidently deeper — at about 200 or 210 m. Off the *Reykjanes Peninsula* (see Section 50 and 51) the general floor of the shelf runs at somewhat similar depths, although it is not so deep off the eastern part (Section 50), as off the western end (Section 51).

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[1] The continental shelf of the Færoes is highest and narrowest on the north and northwest side of the islands, and broadest but also most submerged, on the east and south-east side.

Submarine Fjords. The continental shelf of Iceland is traversed on all sides of the island, by comparatively shallow but well developed submarine fjords[1], which generally form regular continuations of the greater fjords of the coast. They exhibit the following typical differences from those of Norway: they are much shallower, and form shallower incisions in the continental shelf; they are much less branched, and radiate, on the whole, fairly regularly from the inner highlands of the island; they are also much less crossed by barriers, and the bottoms very often slope gradually from the inner ends towards the mouths on the edge of the shelf: nowhere are there found those striking differences between the inner hollows and the shallower parts outside, which are so typical of Norwegian submarine fjords. The excellent charts of the east coast of Iceland published lately by the Søkort-Arkiv in Copenhagen[2], demonstrate very clearly the sculpturing of the eastern submarine fjords. Most of them are shallow in the inner part, whilst the bottoms slope on the whole, regularly towards the mouths; only some few of them (*e. g.* Seydis-Fjord, Fáskrúd-Fjord, Stödvar-Fjord, Beru-Fjord) have deeper hollows near the inner ends, but the difference in depth between these hollows and the barriers outside does not, as a rule, exceed 34 m.; the greatest fjord, Reydar Fjord, which has several hollows of 200 m. with a barrier outside of no more than 134 m., making a difference of 66 m., forms an exception.

An important feature is that the inner hollows of these fjords never descend to depths even approaching those of the mouths of their submarine channels at the edge of the continental shelf, which are at least 250 m. deep, and probably deeper: in this respect there is a striking difference between these fjords and the submarine fjords of Norway.

The submarine fjords of the other coasts of Iceland exhibit, as far as they have been surveyed, much the same features as above; but at some places, especially on the west coast, there are greater differences between the depths of the inner hollows and those of the barriers outside. The Hval-Fjord on the west coast has, for instance, depths of 190 m., while the Faxa-Fjord out-

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[1] The submarine fjords of Iceland has lately been described by Dr. TH. THORODDSEN, 'Islandske Fjorde og Bugter', *Geografisk Tidsskrift*, vol. 16, Copenhagen, 1901, pp. 58 *et seq.*

[2] Islands Østkyst, Langanes-Vestrahorn, Scale 1 : 250,000, surveyed 1898—1900, S. K. A., No. 189, Copenhagen, 1901. See also Nos. 190—194.

side is 25 or 30 m. deep, making a difference of 160 m. The small fjords of Bardastrand have depths of 170 m. while the Breidi-Fjord outside, is only 12 or 15 m. deep; the difference is consequently about 155 m., etc. The depths of the inner hollows of the fjords nowhere exceed, however, 200 m.; while in Norway they generally descend to 400 and 500 m. or more.

The *incisions* of the submarine fjords below the general floor of the continental shelf are not deep; very often, *e. g.* on the east coast, their bottoms stand less than 80 or 100 m. below the tops of the ridges between them. Only in a few fjords are the incisions below the floor of the shelf as much as 160 m. or 180 m. (Breidi Fjord, Huna Floi) and even 240 to 300 m. (Faxa Fjord, Eya Fjord).

As the regular Danish soundings do not exceed 200 or 250 m. it cannot be determined how deep the submarine fjords descend on the edge of the shelf. Dr. THORODDSEN[1] says that "all the fjords descend almost equally deep, and their mouths stand at a depth of about 245 m.; they disappear entirely beyond 250 m., so that we must assume that the coast line was situated at this level, when they were formed:" this seems to me to be a somewhat doubtful statement. It may be that in several submarine fjords, *e. g.* on the east coast, the bottoms are for greater distances at a fairly uniform level of between 200 and 240 m., but as long as there are no regular soundings beyond this depth this does not warrant the statement that they totally disappear beyond 250 m. The known soundings prove that some submarine fjords even on the east coast descend to considerably greater depths. Near the mouth of the *Hjerads-Floi Deep*, on the north-east coast, there is a sounding of 414 m., far inside a line between soundings of 225 m. and 244 m. Nearer land there are several soundings of 254 m. with no bottom. It seems probable that this fjord descends to a depth of at least 414 m., but how much deeper it goes, one cannot say[2]. In the outer parts of *Bakka-Floi Deep* and *Seydis-Fjord Deep*, north and south of Hjerads-Floi Deep, there are many soundings

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[1] L. c., p. 73.

[2] Dr. THORODDSEN (l. c., p. 73) points out the possibility that some submarine depressions, *e. g.* the submarine continuations of Hjerads Floi, Faxa Floi, and Breidi Fjord, are formed by faults or dislocations. But this explanation is hardly tenable for such well defined submarine channels as those for instance, of Eya Fjord and Huna Floi (see later). The Eya Fjord is evidently, as THORODDSEN himself says, a regular and well developed channel of erosion.

of 254 m. with no bottom; in the inner part of Bakka-Floi Deep there is a sounding of 278 m. It is perfectly impossible to determine at present, how deep these and other submarine fjords of the east coast may descend.

On the continental shelf, about 25 kilometres off the mouth of the *Eya-Fjord* on the north coast, a sounding of 403 m. situated between soundings of 132 m., 188 m., and 225 m., is recorded on the Danish charts Nos. 55 and 114 (Edition 1902). About 33 kilometres farther seawards, there is another sounding of 499 m. between two soundings of 301 m. and 314 m. The numerous soundings taken by the Danish survey in this region last summer, prove that this seaward continuation of the Eya Fjord forms a well defined submarine channel or fjord, the bottom of which slopes gently and regularly from the inner fjord of the coast, which is only about 117 m. deep, towards the above mentioned sounding of 499 m. From the mouth of the Eya Fjord, where the depth is about 190 m., the following soundings have been taken seawards, along the middle of this submarine channel: 308 m., 403 m., 430 m., 430 m., and 499 m., beyond which there are unfortunately no more soundings; thus it cannot be stated whether the submarine fjord descends still deeper. The bottom of the Eya Fjord forms an incision of from 1280 m. to 1370 m. below the level of the highest mountains (Rimar, Heljarfjall, Kaldbakr) of the land on both sides, while the bottom of the submarine channel off the fjord is only 340 m. or 360 m. below the tops of the highest ridges of the continental shelf on each side. The *Huna Floi* also forms, according to the charts and the numerous soundings of last year, a well defined submarine channel or fjord traversing the continental shelf. Its bottom lies at a level of between 310 m. and 330 m., and although there may be a few deeper hollows separated by low barriers, it seems, on the whole to slope gently and fairly regularly towards the edge of the shelf, where there is a sounding of 395 m. with minor depths on both sides. Whether this indicates its mouth cannot be decided, as there are no soundings farther seawards; but it is hardly probable. In the inner part of the Huna Floi there are depths of 225 m. and 238 m., which are perhaps among the greatest depths found in any fjord on Iceland. The incision of the Huna Floi Submarine Fjord below the upper level of the continental shelf on both sides, is about 240 m. In the mouth of the *Breidi Fjord*, just north-west of Snæfellsnes, there is a sharply defined submarine channel, *Kolluáll*, with depths of be-

tween 215 m. and 301 m., and very precipitous side slopes from 90 m. to 130 m. high. This channel has a southwestward direction, but its seaward course or its base-level near the edge of the continental shelf, cannot be determined owing to the fewness of the soundings; there are a few soundings of 338 m. between smaller depths. Off *Faxa Floi* or *Faxa Fjord* two soundings of 527 m. and 508 m. are recorded on the charts inside and between depths of 226 m. and 320 m.; whilst nearer the mouth of the fjord or bay there are soundings of 376 m. and 338 m. situated between minor depths. It seems possible that these deeper soundings indicate a submarine fjord or valley traversing the continental shelf and descending at least to 527 m. In *Skeidarar-Deep*, on the south coast, there is a sounding of 290 m., but whether the submarine fjord descends to still greater depths, it is hard to say.

Off the south-east corner of Iceland, between the mouths of the Beru-Fjord Deep and the Lóns-Deep (see Pl. XXIV) there is a remarkable, deep and narrow suboceanic depression or ravine, having apparently, the shape of a river-channel. Its existence is indicated by the soundings recorded on the Danish charts Nos. 55 and 114, but its almost canyon-like shape seems to be still better demonstrated by several soundings taken by Dr. Hjort on board the Michael Sars in the summer of 1902. The bottom of this channel descends to depths of at least 1171 m. and 1182 m. (soundings of the Michael Sars) and even to 1246 m. (the Danish charts); it thus forms an incision in the general sea-floor of at least 600 m., and probably, of as much as 800 or 1000 m. in its inner part. On the west side of the channel, and quite near a sounding of 1171 m., Dr. Hjort took two soundings of only 137 m. and 252 m.; but unfortunately no soundings have been taken near the eastern side of this channel. A little farther east there are, however, a few soundings of 621 m., 659 m., and 640 m., which seem to indicate the level of the platform in this region. The side slopes of the channel seem to be very steep, but cannot be defined, owing to the fewness of the soundings. On the west side of the channel the slope seems to be at least 1 in 8 or 10, or about 6° or 7°. It cannot be decided whether this deep channel actually ends near the edge of the continental shelf, or whether it does not rather communicate both with the *Beru-Fjord* and the *Lóns-Deep*, which, in my opinion, is very possible, although, of course, these two submarine fjords are very much shallower, and their bottoms evidently indicate another distinct and very different level. It seems also

probable that the deep channel receives a tributary from the north-east. The soundings are not at any rate numerous enough to allow us to trace out the outlines of this deep depression with a sufficient minuteness of detail, and we cannot decide, whether it has the typical character of a fjord or channel formed by atmospheric erosion, or whether it may have been formed by faults or dislocations.

It is, however, an interesting fact that the depths of this channel (between 1171 m. and 1246 m.) very nearly coincide with those of the Færoe-Shetland Channel (1170 m. to 1260 m.), as also with those of the suboceanic plains south of the Wyville Thomson Ridge and on the south-west and north side of the Færoe platform.

The folloving Different Levels may possibly be traced out on the Icelandic submarine platform:

(1) The highest ridges and parts of the continental shelf, between the submarine fjords, tend towards a level of about 100 m. below present sea-level. At several places the floor of these ridges slopes down to greater depths with the edge of the shelf at about 180 m. or even at 200 m. below sea-level.

(2) The base-level of most submarine fjords cannot be determined at present, as the regular soundings are not deep enough, but the bottoms lie to a very great extent between 200 m. and 240 m., with the gentle slope running seawards. It seems possible that these depths mark a special level.

(3) It was mentioned above that the submarine continuation of the Eyja Fjord descends to 400 m. and 496 m., and the Huna-Floi to 398 m. These depths indicate perhaps a level, which seems to coincide in a remarkable manner with the base-level of the great submarine fjords of Norway, the Barents Sea, and the North Sea (the Norwegian Channel). On other sides of Iceland we have indications of a similar level, the most remarkable one being the *Færoe-Iceland Ridge.* With the help of the Danish chart Nos. 55 and 114, of Iceland and the Færoes, and of a great many soundings taken on board the Michael Sars in the summer of 1902, we may now form a fairly good idea of the configuration of this ridge (see chart Pl. XXIV and Section 46). Its highest part seems to form a very level plateau, at a depth of between 400 m.

and 500 m. below the sea-surface. Within an elongated area in its middle portion, it seems to rise above a depth of 400 m.; and at one isolated place near the south-eastern end of this area, Dr. Hjort took two soundings of only 324 m. At another place, farther northwest and nearer Iceland, the depth has been found to be 348 m. The lowest part of the ridge seems to be about 90 or 100 kilometres north-west of the Færoes, with depths of between 450 m. and 490 m.; but by a more complete survey these depths may possibly be reduced. The slope of the sides of this ridge is only imperfectly known, but they seem to be fairly steep below the 500 m. or 600 m. contours, especially on the northern side, at least at those places where the soundings are sufficiently numerous to give any information (*e. g.* north of the Færoe Islands and also east of Iceland near 65° N. L.) On the south side of the ridge the slope is on the whole more gentle. Near the narrow canyonlike depression — 1170 m. and 1246 m. deep — off the southeast corner of Iceland the slopes seem, however, to be very steep, as mentioned above (p. 82).

The submarine ridge between Iceland and Greenland much resembles the former ridge, and in its middle portion seems to form a plateau at very similar, perhaps somewhat greater, depths; but in this region the soundings are unfortunately too few and too far between to give any reliable information. Nearer Iceland, but especially towards Greenland, the plateau of the ridge seems to be a good deal higher than the Færoe-Iceland Ridge; on the Greenland side we have for instance, soundings of 350 m. and 273 m. On the whole the soundings, hitherto taken in this region, give the impression that along the coast on the Greenland side of the Danemark Strait there is a broad platform with depths varying between 260 m. and 350 m. From its edge there is a comparatively steep descent towards the abyssmal region on the south side of the Iceland-Greenland Ridge. On the north side of this ridge the soundings seem to indicate that there is a comparatively narrow and deep channel with pretty steep side slopes descending to depths of 658 m. at its southern end, and farther northwards to 1318 m. or even to 1500 m. But the soundings are much too few to enable us to follow the outlines of this channel.

(4) Off the east coast of Iceland a sub-oceanic ridge or plateau extends from the northwestern end of the Færoe-Iceland Ridge, towards the north

or northeast. This plateau seems to slope gently northwards, but the soundings are too few to enable us to trace out the details of its surface relief. In Section 59, it forms a platform gently sloping from 511 m. to about 773 m., (soundings made on board the Michael Sars); but from the latter depth there is a steep descent to 1183 m. and probably much deeper, right down in fact, to the floor of the deep ocean. In Section 58, farther north, the level of the platform is deeper, probably at about 850 m. It seems possible that in this region, the greater part of the topmost ridge of the platform is at similar depths, for in a longitudinal section probably along the ridge, from south towards north, we would have the following soundings: 790 m., 800 m., 841 m., 856 m. the last being about 130 kilometres north of the first one. About 50 kilometres still farther north, there is a sounding of 1090 m., and it seems as if we are here north of the approximately level plateau. It would thus appear that, on this ridge there are indications of a submarine level at depths of between 800 and 850 m.; but as before said the soundings are much too few to say anything with certainty.

(5) Judging from soundings taken during the Ingolf-expedition of 1896[1], a long suboceanic ridge, the *Reykjanes Ridge*, seems to extend from the south-west corner of Iceland towards the southwest. Along a great distance, far down into the North Atlantic, the highest level of this ridge seems to be at depths of between 1230 m. and 1265 m.; but the soundings are much too few to give any trustworthy information on this point. If this level really does exist, the depths recorded very nearly coincide, as we have seen with those of the deep suboceanic ravine off Papos (p. 82), the Færoe-Shetland Channel, and the suboceanic plains round the Færoe platform (p. 73). There is also a great similarity with the soundings on the Vöring Plateau off the northern coasts of Norway (see p. 53, and Section C), and on the Blake Plateau off the American east coast (see later). The deepest hollows of the deepest Norwegian fjord, the Sogne Fjord, descend to similar depths, 1240 m.

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[1] C. F. WANDEL, *The Danish Ingolf-Expedition*, vol. I, Copenhagen 1898.

It seems possible that on the Reykjanes Suboceanic Ridge there are also indications of another level at about 900 m., nearly corresponding to the level of the above mentioned suboceanic plateau off the east coast.

The Continental Slope of the Icelandic submarine platform varies much on the different sides of the island, and is often interrupted by the above mentioned suboceanic plateaus and ridges. It is, as a rule, very gentle, and seems nowhere to be very steep, a somewhat striking fact, considering the volcanic nature of the island. The slope is, on the whole, steepest along the southern coast, from the edge of the shelf to depths of about 1170 m. and 1300 m. But the inclination seems even here to be less than 1 in 20, or 2° 50′, except on the sides of the deep and narrow channel off Papos (see p. 82), where the slope is perhaps as much as 7° or more. Below 1200 or 1300 m. the slope of the sea-bottom is evidently very gentle. Off the northern coast of Iceland the continental slope seems, on the whole, to be unusually gentle; at several places it is about 1 in 110 or 31′. It is probably steepest towards the Iceland-Greenland Channel off the north-west corner, where between the edge of the submarine shelf, at 244 m., and a depth of 1318 m., near the bottom of the channel the slope is possibly 3° or 4° (see Section 53).

VII. THE CONTINENTAL SHELF OF GREENLAND.

Along the greater part of the coast of Greenland there seems to be a well developed continental shelf which much resembles that of Norway. It is, however, only at a very few places that the soundings are sufficiently numerous to give any idea of its surface relief. Along the east coast north of 65° N. Lat. the soundings indicate that there is a broad shelf, situated comparatively deep perhaps, and probably with deep submarine fjords (*e. g.* off the Franz Josef Fjord, the King Oscar Fjord, the Scoresby Fjord, and the Kangerdlugsuak Fjord in 68° N. Lat.) South of 65° N. Lat. the continental shelf of the east coast seems to be much narrower, but there are extremely few soundings in this region, especially near the coast.

Along a great part of the Greenland west coast numerous soundings have been taken, and at several places we are thus able to study the continental shelf somewhat more satisfactorily. Off the Greenland west coast there is evidently a series of banks, similar to those situated off the northern coasts of Norway: where the soundings have been sufficiently numerous, they have demonstrated the existence of important fishing banks, as for instance, *Store Hellefiske Bank* off the Holstensborg District (between 66° 30′ N. Lat. and 68° 15′ N. Lat., *Lille Hellefiske Bank* off the Sukkertoppen District, and the *Fylla Bank* off the Godthaab District (Pl. VI, fig. 4), and scattered soundings in other regions off the coast seem to indicate that there are probably a great many more. These banks seem to be more or less separated by submarine fjords, the outlines and depths of which cannot, however, be traced out owing

to the fewness of the soundings. A very noteworthy fact is that the surface of the above mentioned Greenland banks, lies to a great extent, much nearer the present sea-level than is the case with the Norwegian banks. The minimum depths of the former are generally between 30 and 40 m. and often at great distances from the coast. On *Store Hellefiske Bank*, soundings of 26 m. and 30 m. have been taken at a distance of about 60 kilometres from the coast, whilst on *Lille Hellefiske Bank* and *Fylla Bank* soundings of 36 m. and even of 30 m. have been taken at about 35 kilometres from the coast. On the whole, a very great part of the continental shelf of west Greenland seems to be above the 100-metres contour, and the depths on the banks appear very often indeed, to be less than 50 or 60 m. The edge of the shelf appears in Sections 61 and 62 at about 98 m. and 107 m. In Section 60 there is no distinct edge at similar shallow depths, unless it be not at about 40 m. or 47 m. On the Fylla Bank the edge is probably at depths of between 50 m. and 80 m.; at other places along the coast it may be deeper, perhaps at between 130 m. and 150 m., but this does not seem to be usual. On the northern part of *Store Hellefiske Bank* (in about 67° 40′ N. Lat.) the continental shelf seems to slope gradually for a great distance from the coast (see Section 60), and has perhaps a sharply defined edge at about 300 m. below sea-level and at a distance of 270 kilometres from the coast; from this depth the continental slope seems to descend steeply to depths of 1264 m. and 1700 m. Farther north, off the Disco Island, there is probably a similar continental shelf sloping seawards down to depths of 308 m. and 335 m.: the soundings are, however, much too few in this region to give any trustworthy information. North of the Umanak Fjord there is probably also a broad continental shelf sloping down to similar depths. Along the S.-W.-coast of Greenland, south of Lat. 63° 30′ N., there are very few soundings; the continental shelf is possibly narrower in this region Off the southern end of the land a steep slope seems to descend from near the coast to depths of 2200 m. and 2250 m., at a distance of only 40 naut. miles or 73 kilometres from land.

Several deep and large *submarine fjords* seem to traverse the continental shelf, being continuations of the fjords of the land inside. The most prominant ones are perhaps the following: the submarine continuation of the *Disco*

Bay, where soundings of 590 m., 482 m., and 508 m. have been taken; the submarine fjord passing south-west from *Holstensborg*; the great submarine fjord south of *Sukkertoppen* with its entrance north of the Fylla Bank near Godthaab where a sounding of 452 m. has been taken; whilst south of *Godthaab* there is probably also a submarine fjord, which is a continuation of the great Godthaab Fjord (Pl. VI, Fig. 4). Off the mouth of the Umanak Fjord (71° N. Lat.) there is evidently also a deep and broad submarine fjord with depths of 500 m. Off. *Julianehaab*, on the south-west coast, a submarine fjord descends at least to 433 m. (60° 25′ N. Lat.) and probably deeper (Pl. I). We see the depths of these great submarine fjords are very much similar to those of the Norwegian submarine fjords or perhaps even somewhat greater, as the latter seldom have depths exceeding 400 m. at any great distance from land. The depths of the interior parts of the Greenland fjords themselves are but little known; but they are probably deep. Near Umanak, in the Umanak Fjord (70° 40′ N. Lat.), there are soundings of 725 m. and 749 m.

The Greenland-Baffin-Land Ridge seems to a great extent to be situated at depths similar to the Færoe-Iceland Ridge, but it is very imperfectly known. Its highest part seems to be in the region between Holstensborg and the Cumberland Peninsula, in about 66° 20′ N. Lat. We have here a sounding of 205 m. very nearly in the midle of Davis Strait; but we do not know whether this sounding indicates the level of the highest ridge, or whether it is not merely a more isolated elevation or a part of the Greenland continental shelf. The level of the highest ridge cannot be determined at present, but it seems probable that it is situated at depths at least shallower than 500 m. Towards the south, at least as far as 64° N. Lat., there is evidently a wide extension of the plateau with depths less than 800 m. Farther south there is probably a steeper descent towards depths of 2000 m. and more. On the Greenland side just west of the Fylla Bank a deep suboceanic depression with depths of 1512 m. seems to extend northward into the ridge. It is probably a continuation of the depression west of Lille Hellefiske Bank, in about 64° 30′ N. Lat., which is marked by the embayments of the 800 m. and 1000 m. contours. It seems possible that it also communicates with the great submarine fjord south of Sukkertoppen, mentioned above.

The Greenland-Baffin-Land Ridge seems to have a fairly steep slope on its northern side from a depth of 707 m. down to depths of 1216 m., 1700 m., and 1900 m. Farther north there are so few soundings in the deeper part of the Baffin Bay that very little can be said at present about the sculpturing of this apparently deep basin.

The coast platform. The west coast of Greenland has to a great extent a coast platform which is very similar to that of the Norwegian coast, although it is not so broad and does not seem to be so well developed. As long as the Greenland west coast has not been especially surveyed on the point, it is difficult to form a clear idea of the Greenland coast platform; especially do we want a great many more soundings near the coast. In the Godthaab District, which I know best, there is, for instance, a well developed coast platform, upon a part of which Godthaab itself is situated (see Pl. VI, Fig. 4). The peninsula outside the Godthaab Fjord, on which *Sardlok* is situated, seems, to a great extent, to belong to this coast platform, and on its inner side it is bounded by a series of high mountains, *e. g. Iviangiusset,* 298 m., *Rype-Island* 225 m., *Hjortetakken* 1180 m., *Store Malene* 795 m., *Lille Malene* 420 m., and *Sadlen* 1212 m., etc. How far the coast platform extends sea-wards cannot be decided, but the distance from the utmost small islands of the *Kokøer* to *Narssak* (near Iviangiusset) is 16 naut. miles or 29 kilometres. It is, however, doubtful whether the shallowest part of the Fylla Bank does not actually belong to the coast platform, although this might not seem probable. The charts of Greenland, published by the Danish Government Survey and in *Meddelelser om Grønland,* demonstrate that a coast platform with a great number of small islands and skerries extend more or less continuously along the whole of the west coast from Cape Farewell northward. The Sections 61 and 62 give a good idea of the existence of this platform, but, as is seen in Section 60, it might be doubtful whether the highest parts of the banks off the coast indicate a level, which is distinctly different from that of the coast platform. The coast platform is in Greenland dissected by fjords and sounds in a similar way as in Norway, and it is evidently a perfectly identical formation, although less developed. The heights of the islands and skerries along the coast are perhaps more irregular in Greenland than in

Norway, and the outer islands are often comparatively high. A drawing by Mr. A. Kornerup from Holstensborg in *Meddelelser om Grønland*, Vol. 2, Pl. VIII (Copenhagen 1881), gives an excellent idea of the coast platform in this region (Pl. VI, Fig. 2 gives a reproduction of this drawing). Pl. VI, Fig. 3 gives an idea of the narrow coast platform with low ice-worn skerries along the coast of southern Greenland.

Along the east coast of Greenland the coast platform seems, as far as I have seen, to be but little developed. I think it actually exists at several places along the southern part of the east coast, where I have travelled, but it is narrow and comparatively insignificant.

VIII. THE CONTINENTAL SHELVES OF THE EUROPEAN AND AMERICAN COASTS OF THE NORTHERN ATLANTIC.

THE BRITISH AND FRENCH CONTINENTAL SHELF.

The Continental Shelf of the British Isles and the European west coast farther south has been discribed and discussed by many authors ever since 1849 when Mr. Godwin-Austen drew attention to the peculiar composition of this interesting platform, which is covered by shingle containing littoral shells far out to sea, indicating in his opinion, that once during a period of upheaval, the shore of the Atlantic was situated so much deeper (80 to 100 fathoms) and far from the present coast-line. It is, therefore, innecessary for me to go into detail, but I wish especially to point out that the continuous broad continental shelf from the Shetland Islands to the Bay of Biscay or the north coast of Spain is very level, bearing much resemblance to the platform of the North Sea. The depth is much more uniform than is the case with the Norwegian continental shelf; this is especially so south of Ireland. It has generally been stated that the edge of the British submerged shelf is situated at a depth of about 100 fathoms or 180 m., but this is hardly quite correct. I should rather be inclined to say that the edge of the shelf has, on the whole, a tendency to be situated near a depth of about 150 m. or 80 fathoms, and that its general floor lies to a very great extent between this depth and 100 m. (55 fathoms), especially is this so between Ireland and Spain: the edge and the general floor of the shelf are only at a few places situated nearer the sea-surface. From the northwest corner of Scotland (see

Pl. XXIII) a platform with depths less than 90 m. (50 fathoms), extends towards the Wyville Thomson Ridge (Section 45). Its general floor is situated between 70 and 90 m. Several small islands and rocks (North Rona, Sulisker, Nun Rock, Stack Skerry, Sule Skerry) rise on the platform. Northwest of the Hebrides there are indications of a similar platform, and also off Bloody Foreland at the northwest corner of Ireland, where the 100 m. contour approaches the edge of the continental shelf. Many traces of a similar higher platform which has now to a great extent been destroyed, may also be found farther south. South of Ireland there are for instance, a great many small banks with depths about 100 m. or less, scattered over the continental shelf far out to sea. I may mention Cockburn Bank (82 m.), West Bank (100 m.), Labadie Bank (62 to 79 m.), Jones Bank (71 and 93 m.) and a great many others, without names on the Admiralty charts. The shallowest soundings on the Great Sole Banks are about 126 m., and on the Little Sole Banks 121 m. Shamrock Knoll (108 m.) and Parsons Bank (102 m.) lie 156 and 90 kilometres off Ushant.

I think the continental shelf west of Ireland has a distinct tendency to lie at the before mentioned level of 100—150 m. Between 12 and 27 kilometres from the coast, the sea-bottom sinks down to 100 m., but after having attained this depth it slopes extremely slowly and regularly seawards to a depth of about 150 m. at 110—140 kilometres from the coast. After having attained this depth, the sea-bottom again descends more steeply to 329 m. or 384 m. at the bottom of the depression or submarine channel inside the *Porcupine Bank,* but this latter bank again rises to a depth of 154 m. about 220 kilometres from land. We cannot fail to recognize in these facts a tendency towards a level of less than 150 m.: we see that, on the whole, the levels of the British and the French continental shelf are very similar to those we have traced out on the Norwegian Continental Shelf.

The *Rockall Bank* is, on the whole situated deeper than the British continental shelfs, and, to judge from the Admiralty chart No. 2, its edge is perhaps situated near the 300 m. contour, although it seems to be somewhat irregular. More soundings would, however, be necessary before one could say more about this.

The submarine fjords and *drowned river valleys* of the British and French continental shelf have been studied and described by several authors,

especially Prof. EDWARD HULL[1]. On the Scottish and British continental platform they are, on the whole, much shallower than the Norwegian submarine fjords, and bear, in this respect, more resemblance to the submarine fjords of east Iceland (cfr. pp. 79—80). Their deepest hollows descend very rarely beyond a depth of 200 m., and, to judge from the charts, never exceed 263 m. (144 fathoms). On the edge of the continental shelf, where they can be traced out, *e. g.* off the North Minch, it is found that their mouths are not, as a rule, much deeper than 200 m.; but the submarine fjords are very often not traceable for long distances across the continental shelf, and very often they disappear before they reach the edge of the shelf. Their deepest hollows are always separated by barriers or banks from the deep sea outside the continental shelf. Some of the deepest hollows of the submarine fjords are in the Little Minch, between the Hebrides and Skye, 208 m.; in Inner Sound inside Raasay there is a depth of 243 m.; in the Sea of the Hebrides, northwest of Tiree, there are hollows descending to 194 m.; in the Sound of Jura there are depths of 219 m. The greatest depth in North Channel between Copeland Island and Mull of Galoway seems to be 263 m. The greatest depths of the Irish Channel are only about 152 m., and those of St. George Channel about 117 m. The Hurd Deep in the English Channel is 174 m.

On the edge and on the declivity of the continental shelf off St. Georges Channel and the English Channel there are evidently several deep cirque-like ravines descending along the continental slope to considerable depths. On the edge of the shelf between Great Sole Banks and Little Sole Banks there seems to be a fairly well developed submarine valley in which two soundings of 1037 m. (567 fathoms) and 1454 m. (795 fathoms) are recorded on the Admiralty Chart No. 2. Nearer the edge of Little Sole Bank there is another valley with a sounding of 777 m. (425 fathoms) far inside the edge of the shelf. Between these two valleys there is a deep cove, with soundings of 1262 m. (690 fathoms) and even 2156 m. (1179 fathoms). On the edge of *La Chapelle Bank* there is an evidently narrow incision with a depth of 1116 m. (610 fathoms). It might seem possible that this channel descends to the sounding

[1] EDWARD HULL, 'Further Investigations regarding the Submerged Terraces and River Valleys bordering the British Isles', *Trans. Victoria Inst.*, vol. XXX, 1896—7, p. 305. See also BOYD DAWKINS, JUKES BROWNE, T. RUPERT JONES and other previous authors.

of 3475 m. (1900 fathoms) which is situated off La Chapelle Bank, in a line with soundings of about 1940 m. It seems impossible at present to determine with certainty, what these depressions on the edge and on the declivity of the continental shelf really are. It may not be improbable that they indicate the outlets of channels of the rivers which drained the regions of the English Channel, St. Georges Channel, etc., when the land stood so much higher.

The *Fosse de Cape Breton*, at the head of the Gulf of Gascony, is a very remarkable and interesting submarine channel, which was explored in 1880 by the Travailleur expedition, and was assumed by ALPHONSE MILNE-EDWARDS[1] to be the ancient bed of the river *Adour*. It descends comparatively rapidly along a winding course, from near the coast, to a depth of 1120 m., at about 40 kilometres from the head of the channel at Cape Breton. From this sounding its bottom slopes very gently for a distance of 18 kilometres to 1160 m.[2]. The course of the channel beyond this point cannot be traced out, as there are no soundings to the north, but I think there is a possibility that Prof. Hull and others are correct when they continue the channel seawards and connect it with the depression, 2200 m. and even 2800 m. deep, at about 30 kilometres off the Spanish coast at Bilbao. If this really is the embouchure of the channel, the chart of the place given by Prof. Milne[3] seems to prove that it has, at any rate, a wider form than assumed by Prof. Hull. The nature of this remarkable channel has been much discussed; but it seems difficult to explain, at least that part of it which is situated above 1160 m., in any other way than as an ancient river bed, as is already done by MILNE EDWARDS, HULL, and others; the channel has evidently the typical winding course of a river bed, receiving lateral tributaries.

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[1] *Bulletin de la Société de Geographie*, vol. III, Paris, 1882, p. 113 and chart No. 1. For discussions of this channel see: J. Y. BUCHANAN, *Scottish Geographical Magazin*, vol. III, 1887, pp. 223–224; ERNST LINHARDT, 'Ueber unterseeischen Flussrinnen', *Jahresbericht der Geographischen Gesellschaft, München*, 1890–1891, p. 26; EDWARD HULL, *Geographical Journal*, vol. XIII, 1899, pp. 287–288; *ibid*, 'On the Suboceanic Terraces and River Valleys off the Coast of Western Europe', *Trans. Victoria Inst.*, April 1899, Authors copy, pp. 12–13; WILFRED H. HUDLESTON, *Geol. Mag.*, vol. VI, 1899, pp. 150–152; HENRY BENEST, 'Submarine Gullies, River Outlets', etc., *Geographical Journal*, vol. XIV, 1899, pp. 405–407, and others.

[2] Cf. the soundings of the *Travailleur*, l. c. chart No. 1.

[3] *Geographical Journal*, vol. X, London 1897, p. 273.

Coast Platform. A coast platform does not exist to any great extent along the west coast of Europe. To judge from the Admiralty charts, a narrow coast platform, with numerous skerries and shoals, extends along the western coast of Scotland and the Hebrides, and also along some parts of the west coast of Ireland. Whether the coast platform also exists inside the coast, on the present land surface, similarly to the Norwegian one, I cannot decide at present, as I have not the necessary maps at hand; but it seems to me to be probably the case at several places. It is a striking fact that there is apparently no coast platform in the Orkneys and the Shetland Islands. Along the greater part of the southern English coasts and the French coast there is no coast platform similar to the Norwegian one. It seems, however, probable that the narrow fringe of skerries and shoals along the rocky coasts of Bretagne might deserve the name of coast platform; they have evidently been much cut back by marine denudation.

THE NORTH AMERICAN CONTINENTAL SHELF.

The continental shelf of the American coast of the North Atlantic, from Newfoundland to about 34° N. Lat. is well developed with a sharply defined edge and an abrupt continental slope. Its width is, as a rule, between 130 and 220 kilometres; off Newfoundland, on the Great Bank, it is about 450 kilometres broad, and off Cape Hatteras it narrows to only 25 or 30 kilometres about. This extensive shelf is, on the whole, very level, and is covered by very shallow water; the sharply defined edge is situated at depths of about 75 m., whilst in front of it there is often a narrow shelf reaching to a depth of 120 to 150 m. The general floor of the upper great shelf slopes gently from 20 m. or less, near the shores, to the edge, and is thus, on the whole, situated nearer the present sea-level than that of the European continental shelf; and it evidently bears in this respect much resemblance to the shelf north of the Siberian coast.

Between 34° N. Lat. and the Bahama Islands (in 27° N. Lat.) the continental shelf widens to a broad platform, of 390 kilometres width, which however, lies at two distinctly different levels: the shelf of the upper-level is comparatively narrow, from 70 to 120 kilometres broad, and slopes from the coast to a depth of about 70 or 80 m., beyond which there is a steeper descent separating it from the plain of the lower level, the *Blake Plateau.*

This plain or shelf is 260 kilometres broad, and its general floor seems to slope very gently from a depth of about 850 m. towards its edge, which seems to a great extent, to be situated between 1000 m. and 1200 m., a depth which approximately coincides with that of the Færoe-Shetland Channel, etc. (cf. pp. 74, 85).

A great many *submarine river-channels and fjords,* traverse the North American continental shelf,[1] but having had no opportunity of studying the detailed coast charts I shall not go into detail on this point, nor can I form any reliable, independent opinion whether the soundings hitherto taken, prove the existence of submerged river-channels descending along the suboceanic continental slope to depths as great as 3600 m., or even more, as assumed by Prof. J. W. SPENCER[1].

The greatest and most conspicouous submerged river-channel or fjord of the northern part of the American east coast is that of the *St. Lawrence Gulf*[2], the dimensions of which bear much resemblance to the Norwegian Submarine Channel and the Barents Submarine Channel. In its inner part, near Anticosti, the St. Lawrence Submerged Channel descends at one place to a depth of 570 m. and at another to 549 m. For a distance of 520 kilometres the bottom of the channel lies at a very uniform depth of between 420 and 530 m. We see, that the bathymetrical features of this submarine fjord are very similar to those of the Barents and Bear Island Channel, the outer part of the Norwegian Channel and other Norwegian submarine fjords (cf. p. 49, and also pp. 83, 89). At the mouth of the St. Lawrence Channel, on the edge of the continental shelf, there is a deep, narrow indentation descending to a depth of 1117 m.

In the *Gulf of Maine*[3] there is a great submerged fjord with several branches and barriers. The greatest depths in the inner parts of this fjord are about 330 m., but near its mouth there are depths of 567 m. and 572 m. At the mouth of the fjord there are several deep, and evidently well defined indentations in the edge of the continental shelf; especially is there one

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[1] J. W. SPENCER, 'Reconstruction of the Antillean Continent', *Bull. of the Geol. Soc. of America,* vol. 6, 1895, pp. 111 *et seq.* *Ibid.* 'On the Continental Elevation of the Glacial Period', *Geol. Mag.* Dec. 4, vol. V, 1898, p. 35.

[2] J. W. SPENCER, 'The High Continental Elevation preceding the Pleistocene Period' *Bull. of the Geol. Soc. of America,* vol. 1, 1890, p. 67.

[3] Cf. J. W. SPENCER, l. c. 1890.

with a depth of 1244 m. between banks having soundings of 115 m. and 179 m. on each side, which thus forms an incision of more than 1000 m. below the floor of the shelf.

The submerged Channel of the *Hudson River* has been described by LINDENKOHL[1]. In moderne time it has evidently been much filled up near land, but near the edge of the continental shelf it has been traced down to a depth of 863 m. below sea-level; it thus forms an incision of about 680 m. below the floor of the continental shelf.

The sharply defined edge of the *Great Bank* of *Newfoundland* is indented at several places. Between this bank and the smaller bank to the east there is a deep indentation, coming from the south, with a depth of 1260 m. (in 46° 36′ N. Lat. and 47° W. Long.[2]). Off the north east coast of Newfoundland there seems to be a deep submarine fjord which is a continuation of Trinity Bay, with depths of 455 m. near its inner end. Near the edge of the continental shelf probably at its mouth, there is apparently a deep channel or an embayment with depths of 741 m., and farther seawards of 1357 m., or of even 2103 m. between minor depths on both sides[2]. But owing to the fewness of the soundings nothing more can be said of this fjord or channel. Northeast of Bell Isle Strait, between Newfoundland and Labrador, there is evidently also a prolongation of the strait to a submarine fjord with depths of about 457 m.[2].

A *Coast Platform* (using the word, as we have applied it to the case of Norway and the west coast of Greenland) does not exist along the greater part of the North American east coast. But, to judge from the charts, a fairly well developed coast platform, with numerous small islands, skerries, and shoals, evidently does exist along the eastern coasts of Labrador and Newfoundland, and to some extent even of Nova Scotia and perhaps of Maine. If the coast platform exists farther south it is not, at any rate, distinctly separated from the shallow inner part of the continental shelf.

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[1] *American Journal of Science,* vol. XXIX, 1885, p. 475; and vol. XLI, 1891, p. 490. DANA drew first attention to this interesting feature, cf. DANA, Manual of Geology, 1863.

[2] Cf. chart No. 21 a, North Atlantic Ocean, Sheet 1, published by the *Hydrographic Office, Washington.*

IX. THE ORIGIN OF THE CONTINENTAL SHELVES.

After having described in the preceding chapters the continental shelves along the coasts of the northern seas, I will try to discuss the possible origin and formation of these shelves.

The submerged valleys and fjords and also the continental shelves along the east coast of North America and the west coast of Europe, have recently been discussed by several geologists and geomorphologists, *e. g.* LINDENKOHL[1], ERNST LINHARDT[2], J. W. SPENCER[3], WARREN UPHAM[4], EDWARD HULL[5], WILFRID H. HUDLESTON[6], HENRY BENEST[7] and others. Some of these authors,

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[1] LINDENKOHL, *American Journal of Science*, vol. XXIX, 1885 p. 475; and vol. XLI, 1891, p. 490.

[2] E. LINHARDT, 'Ueber unterseeische Flussrinnen', *Jahresbericht der Geograph. Gesellsch. in München* für 1890—1891, Munich 1892, p. 21. Gives an account of previous literature on the subject.

[3] J. W. SPENCER, 'Reconstruction of the Antillean Continent', *Bull. Geolog. Society of America*, vol. 6, Rochester 1895, p. 103, and other works by the same author.

[4] WARREN UPHAM, 'Quarternary Changes of Levels', *Geol. Mag.* Dec. 3, vol. VII, 1890, p. 492; 'Cause of the Glacial Epoch', *Trans. Victoria Inst.*, vol. XXIX, p. 121; 'Fjords and Submerged Valleys of Europe', *American Geologist*, vol. XXII 1898, p. 101.

[5] EDWARD HULL, 'Further Investigations regarding the Submerged Terraces and River Valleys bordering the British Isles', *Trans. Victoria Institut.*, vol. XXX, 1896—97, p. 305; *Geograph. Journal*, vol. XIII, 1899, p. 285; 'On the Sub-Oceanic Terraces and River Valleys off the Coast of Western Europe', *Trans. Victoria Inst.*, April 1899. Since the above had been written Prof. Hull has kindly sent me a new paper: 'The Physical History of the Norwegian Fjords', *Trans. Victoria Inst.*, February 1902. See also W. P. JERVIS, 'Thalassographical and Thalassological Notes on the North Sea', *Trans. Victoria Inst.*, April 1900.

[6] WILFRID H. HUDLESTON, 'The Eastern Margin of the North Atlantic Basin', *Geol. Mag.* Dec. 4, vol. VI, pp. 97, 145.

[7] HENRY BENEST, 'Submarine Gullies, River Outlets, and Fresh-Water Escapes beneath the Sea-Level', *Geograph. Journal*, vol. XIV, 1899, p. 394.

especially SPENCER, UPHAM, and HULL, have strongly urged that the bathymetrical features of the submarine channels of the continental shelves and the submerged continental slope, prove that great vertical, epeirogenic movements of the coast must have occurred comparatively recently; the Antillean Islands must once have been elevated 12000 feet (3600 m.), and the coast of the Bay of Biscay and the coast of Portugal have been at least 9000 feet (2700 m.) higher than at present. Prof. SPENCER believes he is able to prove that, on the coasts of the Antillean Islands and America, there has been a series of vertical oscillations of this kind above and below the present sea-level. As regards the continental shelves, the opinion of several authors, *e. g.* Prof. HULL, seems to be, that they have been formed before the submerged valleys, probably in late Tertiary times, and chiefly by marine denudation ("Abrasion") during a period of slow, gradual submergence of the coast. Afterwards the shelves have been elevated into dry land, perhaps several times; their originally more or less level surfaces were afterwards sculptured by atmospheric erosion, and then trenched by river channels and valleys. Finally the shelves were submerged to their present levels. Other authors seem to be of the opinion that the continental shelves have chiefly been formed by deposition of sediments near the coasts.

In a lecture delivered before the Academy of Sciences of Christiania, some time ago (November 22, 1901)[1] I drew attention to the fact that the depths of the continental shelves and their edges, were extremely similar in the North Polar Sea and on the coasts of Europe, etc., with the exception that on the whole they seem to be somewhat nearer present sea-level in the former region. I urged that if we accept the above theory that the continental shelves were formed chiefly previous to the submerged valleys, then we are of necessity led to the assumption, that the great changes in sea-level proved by the submerged valleys, cannot have been due to vertical movements of the Earth's crust (the lithosphere), but must have been caused by great oscillations of the hydrosphere, while the lithosphere has remained comparatively stable during this period. It would make little difference in this respect, whether the shelves were originally cut by wave-action in solid rock, or were also built up, more or less, by coast deposits. When we consider that

[1] Cf. *Forhandl. i Vid.-Selskabet*, Christiania, 1901, Oversigt p. 42.

the continental shelf of Portugal (and even of Africa), Spain and France is continuous with that on which the British Isles are situated, and that this again is continuous at least to some extent, right across the North Sea, with the continental shelf of Norway and farther north again with that of the Barents Sea, Spitsbergen, the Franz Josef Archipelago, and the Siberian coast as far east as the Bering Sea, then I argued, on the assumption that this extensive platform is *the same formation dating from the same period* (*i. e.* late Tertiary or Post-Tertiary) and if we furthermore can prove that this platform — *e. g.* in the Bay of Biscay, on the British-Irish coast, on the Norwegian coast, and in the Barents-Murman Sea — has been emerged into dry land, and at some places has stood perhaps several thousand feet above sea-level, and has subsequently again been submerged to its present level, we are simply forced to the conclusion that the platform has undergone the same oscillations of level along its whole length; it is most improbable, if not to say impossible, that isolated parts of the platform could have been elevated to such great heights, and should afterwards have happened to have sunk down to form anew, the original level plane along the whole distance. But considering that this continental shelf is continuously extended over a distance (from Africa to the Bering Sea) equal to one fifth or one quarter of the Earth's circumference, we should thus with equal certainty, be compelled to assume that these great oscillations of level have not been due to direct vertical movements of the Earth's crust (the lithosphere), but *must have been due to oscillations of the hydrosphere.* For it would seem inconceivable that the lithosphere would be able to undergo such regular and extended vertical movements or pulsations; it seems probable that folds and faults would then occur along the moving coasts, by which the plane of the extensive continental shelf would be much disturbed or distorted. The existence of the Eurasian continental shelf and its present surface-sculpturing with submerged valleys, which at some places reach down to great depths along its declivity, would then be an excellent and conclusive proof of previous great oscillations of the level of the hydrosphere, in late Tertiary and Post-Tertiary times, whatever the causes of these oscillations might have been.

But the validity of this proof would naturally stand or fall with the theory that when the Eurasian and American continental shelves were first formed,

they acquired very nearly the same general floor as they have at present, and likewise to some extent with the theory that the shelves have been formed before the present submarine channels and fjords. But before we enter upon a discussion of this subject, we ought to settle another important question, *how may continental shelves be formed?* This is, however, a much more difficult question than it may appear at first, because the now submerged continental shelves are not accessible to direct observation. The best course to follow, before we enter upon this problem, would, therefore, be, if possible, to examine similar formations which have now been emerged into dry land. The coast platforms of Norway and other lands, is a grand formation much resembling these continental shelves, at least in several respects, and the chief events of their history is, I believe, comparatively easy to read.

THE FORMATION OF THE COAST PLATFORMS.

It has been mentioned above, that coast-platforms probably exist along the coasts of Siberia (pp. 20—22), Norway (pp. 39, 44, 51—52, 60—61), Greenland (p. 90) and perhaps also to some extent along the coasts of Scotland and Ireland (p. 96), Newfoundland and Nova Scotia (p. 98), etc., while there is practically no coast platforms along the coasts of the Færoes and the greater part of Iceland (pp. 71—72, 75—77).

We have seen that, what I have called the coast platform of Siberia and Russia, is in many places cut of solid rock, *e. g.* the islands at the north-eastern corner of the Chelyuskin Peninsula (Pl. IV, fig. 2), Cape Chelyuskin (Pl. III, fig. 3 and 4), Kjellman Islands (Pl. III, figs. 8, 9 and 10; Pl. IV, fig. 1), Yugor Strait (p. 22, and Pl. III, fig. 12), and probably also on the Tillo Islands (Pl. III, fig. 7). At other places — *e. g.* the lands near Taimur Sound (Pl. III, figs. 5, 6), and on Kamenni or Rocky Island (Pl. III, fig. 11) — there is a low fore-land evidently corresponding to the coast platform, which is probably to some extent cut in solid rocks, but is also partially built up of sand or clay: this low land is surmounted by fairly low, rounded hills. On Kamenni (fig. 11) a few shore-lines could be distinguished above the low land. For great distances, the Siberian coast is formed by low

land, the level of which corresponds approximately to that of the coast platform cut in the solid rocks, but it is apparantly very largely built up of glacial drift, alluvial deposits, and probably also modern marine deposits. I may, for instance, mention the coast of Yalmal, (Pl. IV, fig. 3), and the coast of Toll Bay (p. 21). I fancy that great parts of the low fore-land along the west coast of the Chelyuskin Peninsula (Pl. III, fig. 3), and the coasts of the Eastern Taimur Peninsula, Pl. III, (figs. 1 and 2) are built up in a similar manner; although at some places, solid rocks *in situ* were also seen on the surface of the fore-land.

I may mention in this connection that at several places along the coasts of the *Franz Josef Archipelago* I observed a broad ledge at the foot of the steep talus of the basaltic mountains. This ledge was broader than an ordinary shore-line or raised beach, of which several were observed and measured, and stood approximately at about the same level at each place. This ledge was always covered by rounded water-washed boulders and pebbles, but at some places it was cut in the basaltic rocks *in situ, e. g.* near our winter hut on Cape Norway and on Mary Elisabeth Island etc. At Cape Flora (Pl. IV, fig. 5) there was a fairly broad ledge with a height of between 13 and 16 m. above sea-level. Its surface was covered by heaps of fairly large, water-washed boulders, rounded by the surf; but the terrace itself had been cut in the soft Jurassic and Pre-Jurassic sediments[1].

On *Spitsbergen* there is also a similar low and flat fore-land at a good many places, to judge from the illustrations of several travellers.

On *Novaya Zemlya*, at least in some places, there is evidently a coast platform very similar to that which I observed, cut partly in solid, soft rocks along the coasts of Yugor Strait, both on Waigach and on the continent. The photograph on Pl. IV, fig. 4 was taken by Mr. WILLIAM S. BRUCE[2] at Cape Cherni (70° 50′ N. Lat., 53° 26′ E. Long.), and is an excellent illustration of this platform, partly cut in solid rocks and partly built up of loose materials.

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[1] Cf. this report, vol. I, No. 2, p. 9. See also, F. Nansen 'Fram over Polhavet', 1897, vol. II, p. 525.

[2] WILLIAM S. BRUCE, 'With the Yachts "Blencathra" and "Princesse Alice" to the Barrents and Greenland Seas', *Scottish Geogr. Mag.*, vol. XV, 1899, p. 116.

In the North of *Bear Island* there is an extensive low plain, which according to JOH. GUNNAR ANDERSON has been formed by marine denudation[1]. But this plain is situated higher than the Norwegian coast platform; it has a mean height of 50 m. above sea-level, and rises from the steep cliffs of the coasts, on an average 25 or 30 m. high, regularly and very gently landwards, to a height of nearly 100 m.[1]

From what Capt. OTTO SVERDRUP has told me there seems to be an extensive low fore-land along the west and north-western coasts of the new lands explored by him and Capt. ISACHSEN. This low fore-land was bounded by highlands with steep declivities, and it seems to much resemble the low fore-land we observed on the Taimur Peninsula. It is thus seen, that a low fore-land, partly cut in solid rocks, and partly built up of loose materials, is a very universal facture of the coasts of the northern seas.

The *coast platform of Norway* is by far the best known low fore-land, and I believe its formation is most easy to study. It is, as we have seen, often 40 and sometimes 60 kilometres wide, that is to say, as wide as or even wider than, the continental shelf at many places. Its surface is chiefly formed by solid rocks, the depressions of which are not, as a rule, filled up to any great extent by waste or glacial drift. At most places the naked, rounded knolls and ridges of rocks are seen on the surface at short intervals, and the fjords and sounds between the islands and shoals are open, so that there is a broad *skjærgaard* formed. At some places, *e. g.* on Jæderen and on Lister, the depressions between the projecting rocks are filled up with loose matter, which consists to a great extent of glacial drift (cf. p. 66). A low continuous fore-land has thus been formed in front of the steeply ascending highlands behind, the whole bearing a striking resemblance to that of the Taimur Peninsula (Pl. III, figs. 1—3).

The Norwegian Coast Platform has been formed by Marine Denudation after the Fjords.

The many sections, Nos. 11—34, demonstrate clearly, how the coast platform forms an often very broad horizontal incision in the steep coast. We see how at most places, the level of the coast platform is distinctly different

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[1] JOH. GUNNAR ANDERSON, *Bull. of the Geol. Inst. of Upsala,* vol. IV, Part 2, No. 8, 1899 pp. 248, 278.

from that of the continental shelf, but on the other hand there is a still more striking difference between the platform and the higher land within. Even considering that the vertical scale of the sections is exaggerated 50 times, it must strike one, how the land rises abruptly from the inner margin of the platform, and it is apparent that the latter must have been cut somehow or other in the solid rocks of the coast. I think there can be little doubt but that this coast platform has been formed by marine denudation[1], which however, has been vigorously assisted by atmospheric erosion. In accordance with other authors my view is that the marine denudation has the most favourable conditions, when the coasts are quite slowly submerged; but I do not believe that a submergence is always necessary, and I do not consider it possible that the broad Norwegian coast platform can have been formed during one period of submergence; I think it must have been formed during long periods of oscillations of the sea-level, chiefly above its present situation, and, moreover, that at the same time there has probably been a very effective atmospheric erosion.

Most authors seem to agree that the many fjords and channels now traversing the Norwegian coast platform were eroded *after* the platform had been cut (cf. REUSCH, DAVIS, VOGT). I see no reason for accepting this theory; on the contrary, *I consider it impossible that a broad and very gently sloping coast platform*, as that of Nordland for instance (40—60 kilometres wide, and sloping only 6 or 7′), *can be formed on a high coast, whis is not deeply dissected by fjords.* If, in general, a broad plain of marine denudation (Richthofens "Abrasionsfläche") actually can be formed on smooth, undissected coasts, which are slowly submerged, as assumed by RICHTHOFEN and others, its slope must at any rate, become much steeper than that of a coast platform. In the extremely shallow sea over a submerged, nearly horizontal and undissected coast platform, the force of the waves would be broken long before they reached the shore; there would also be little opportunity for the waste formed by marine denudation, as well as the waste carried by the rivers, to be washed away into deeper waters, except by tidal currents and wind currents, it would in fact greatly reduce the progress of

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[1] This has also been assumed by previous authors, cf. BRØGGER, REUSCH, VOGT, and DAVIS, see *ante* foot-note p. 51.

marine denudation; all coarse matter would be carried towards land by the waves, heaped up against the base of the cliffs as a beach, and effectually protect them against wave action.

On a coast much dissected by deep fjords the conditions are entirely different. It has been aknowledged by previous authors that the marine denudation is much impeded by the accumulation of the waste formed by the wave action, and still more by the waste carried into the sea by rivers[1]. But as the latter depends on the drainage area of the rivers and also on the height of the land, the marine denudation must be less effective on coasts with an extensive highland behind than on coasts of limited low areas, and it must be more effective on coasts of small islands than on continental coasts. It has also been aknowledged that these conditions are much modified by the tides and sea-currents, by which the waste may be carried away. But it has not, I believe, been fully realized of what great importance it is, in this respect, that *the coast and the sea-bottom outside, have been dissected by deep fjords and channels before the marine denudation begins its work.* The shore-line of the land has become very long as compared with its area, and many times longer than that of a smooth coast. The islands and promonteries of the outer coast line will be attacked from several sides by the wave action[2], the waste will everywhere have an easy access into the deep water of the channels until they are entirely filled up, and so no beaches will be built up along the base of the cliffs; the force of the wave will not be broken in shallow water far off the coast, to the same extent as in the case of a shallow undissected coast; the waves may follow the deep channels and they will not carry coarse matter, pebbles, etc., towards the shores, but will drop them on the way into the deeper waters of the channels. On such a much dissected coast the marine denudation may produce great effects even at a more or less stationary sea-level, but secular vertical oscillations of the shore-line will naturally increase the effect of the wave-action. The tidal oscillations will have a great effect in this respect, as the surface attacked

[1] Cf. for instance, A. PENCK, Morphologie der Erdoberfläche, vol. II, 1894, pg. 477, 490.

[2] Dr. ANDR. M. HANSEN (*Arch. for Math. og Naturvid.*, vol. XVII, Christiania, 1894, No. 5, p. 14) is evidently of a somewhat similar opinion when he says, 'that there have been opened serial lines of attack for wave action and the drifting ice along the intervening original sounds', and he maintains that the broad coast platforms are simply several shore-lines which have met and united. I do not, however, agree with HANSEN that the drifting ice has been an agent of importance for the formation of the coast platform.

by the waves is much increased, and the work of the frost will also get more favourable conditions. If there are rapid sea currents the marine denudation of such a much dissected coast is also largely increased.

It is of very great importance that the subaerial erosion, *i. e.* atmospheric and glacial erosion, is considerably more effective on a deeply dissected coast than on a smooth coast: for on the steep small islands, and on the steep narrow peninsulas between the fjords, the waste has a short way to travel to reach the sea, and fresh rock surfaces are constantly being exposed to the attack of running water, ice, frost, wind, etc. These islands and peninsulas are therefore cut down comparatively rapidly, and are literally washed into the sea. Here and there hills and peaks which were originally of very great size, or were composed of very resistant rocks, may still remain surmounting the platform as solitary outposts of the former high land, which has not yet entirely succumbed (Pl. V, figs. 1, 4; Pl. VI, fig. 1).

There is still a third point of much importance: a deeply dissected coast is much more rapidly cut back by marine and subaerial denudation than an undissected coast, simply because there is much less matter above sea-level to be cut away, most of the work having already been done beforehand When Prof. VOGT says that the thickness of rock cut away during the formation of the coast platform in Nordland, is 400 m., and in northern Helgeland perhaps 500 m., that means an enormous quantity, if we assume it to have been a solid block of rock; but it will only be a small fragment of this quantity, if the land was already dissected by fjords before the platform was formed, and then had a surface relief similar to, or probably even more dissected than the present coast.

There is according to my view no proof that the present Norwegian fjords have been formed after the present coast platform. Prof. VOGT urges (*l. c.* p. 52) that the absence of a coast platform in the inner fjords makes it probable that the platform was formed before the fjords. I cannot accept this argument for the following reasons: 1) the effect of the marine denudation is very much reduced inside the mouths of the fjords, whilst in the inner narrow fjords it is comparatively insignificant, and hardly greater than in a lake,[1]

[1] Sea-water does not expand suddenly when it is transformed into ice, and it has not therefore the same ability as fresh-water to splinter the rocks during frost, cf. Prof. O. E. SCHIØTZ, *Forh. i Vid.-Selskabet, Christiania,* 1894, No. 4, p. 17.

except perhaps where the tide is considerable. 2) If small coast platforms or shore-lines, had been formed in the fjords during pre-glacial, or inter-glacial times, they would have been more or less obliterated by the violent scouring of the glaciers during the next glacial epoch[1]. 3) Prof. VOGT does not seem to have considered the possibility that the fjords may have been filled by glaciers during a great part of the time when the coast platform was carved by marine denudation on the ice-free coast outside.

By considering the present surface relief of the Norwegian coast platform we also arrive at the conclusion that the deep and narrow fjords and channels have existed to a great extent, when the comparatively flat and square upper surfaces of the saliences between them, were cut to form the coast platform (cf. Sections Nos. 20 *et seq.*); for else it would be difficult to understand why the agencies carving the deep channels did not also sculpture the saliences between them to a much greater extent, and make them more like the peaks of the land within than is now the case. On the other hand it has to be considered that the marine denudation has most favourable conditions during periods of submergence of the coast, and the ledges then formed round each island must naturally attain appreciable slopes; then the upper surfaces of the different islands, skerries, and shoals of the coast platform cannot become quite square and horizontal, but must be more or less rounded and with sloping sides (Pl. V, fig. 4). It has also to be duely considered that the surface of the coast platform is ice-worn at many places; it has evidently been eroded by glaciers during the latest glaciation of the coast; but nevertheless the great features of the surface relief of its rocks, have the appearance of being very young, and they cannot possibly have been much altered by glacial erosion since its prime formation, nor has much lowering occurred.

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[1] I do however, consider it possible that in some fjords we may still find traces of ancient sea-levels corresponding to some extent to that of the coast platform. I think, for instance, that the possibility is not entirely excluded, that such traces excist in the inner part of the Christiania Fjord. The comparatively uniform heights of the many ridges of Silurian rocks on the many pininsulas and islands near Christiania (*e. g.* Bygdø, Fornebo Peninsula, Næsø, Ostø, Eljarnes, Steilene, etc., etc.), might indicate a sea-level to which the soft Silurian rocks of this land was once abraded. The land has evidently afterwards been much sculptured and altered by glacial erosion, but traces of the ancient sea-level may nevertheless still exist.

The last glaciation, however, may have been important in producing the present configuration of the Norwegian coast platform, by sweeping away a great part of the waste which had been accumulated during the previous denudation of the platform, the deep channels and fjords of which have thus been more or less re-opened, whilst on the other hand, they could not be completely refilled again with glacial drift.

The occurrence of glacial periods probably greatly forwards the formation of a coast platform, and chiefly in the following ways:

1. The glaciers of the repeated glacial epochs will carry away seewards the waste covering the land and silting up the fjords; when the glaciers retreat, fresh rock surfaces will be exposed to the attacks of wave action, tides, currents, and atmospheric erosion, and the rate of denudation will be much increased.

2. The severe climate with much rain, frost etc., preceding, accompanying and succeeding each glacial epoch of the coast, must greatly increase the atmospheric erosion and denudation.

3. The slow and repeated vertical oscillations of the shore-line caused by the isostatic movements of the land under the pressure of the ice-caps, will greatly favour the marine denudation. Small oscillations of sea-level have occurred through the accumulation of water in the ice-caps, by which the volume of the ocean was altered; and also, though slightly, as a result of the influence exerted on the sea-level by the attraction of the ice-masses on land.

4. The 'ice-foot' and the drifting ice formed along the coasts of a glaciated land, prevent the growth of sea-weed, barnacles and moluscs near the shore-line, which otherwise protect the shore against wave action.

According to what has been said above, *a necessary condition for the formation of a broad coast platform along a high coast is, that the coast has been much dissected by deep, long fjords and sounds before the marine denudation began its work.* But this does not infer that the coast is still much indented; where the fjords and submarine channels have not recently been re-opened by glacial erosion, they may have been filled more or less by marine or alluvial sediments or by glacial drift, and the coast platform may thus have been transformed into an extensive level, or gently rolling plain, on the surface of wich the rocks project here and there. *Jæderen* and probably also the *Listerland,* on the south-west coast of Norway, are examples of such

formations. Such plains formed from a filled-up coast platform and flanked by a highland may, however, especially from a distance, much resemble alluvial plains formed above sea-level at the foot of steep mountains (*e. g.* the plains of the Po) or also plains of marine deposits which were laid down below sea-level, outside a high coast; and before the nature of their deposits has been more thoroughly investigated it may consequently be difficult to definitely decide, which is the exact mode of formation of such-like plains.

An important difference between the plains of a filled-up coast platform originally cut in solid rock as above, and alluvial plains or marine plains should be, that on the former, ridges of rocks *in situ*, generally project here and there, or the rock surface may even be exposed over fairly extensive areas. This is the reason why I believe that the low and level fore-land in front of the higher mountains of the Taimur Peninsula (Pl. III, figs. 1—3) must actually be an ancient coast platform which has been filled up more or less, for at many places the rocks *in situ* are exposed, standing at a very regular level (Pl. III, fig. 4; Pl. IV, fig. 2). On the low land on both sides of the Yugor Strait (Pl. III, fig. 12) the Silurian rocks *in situ* are also exposed here and there. At several places the Siberian coast is still intersected by fjords and sounds, and is fringed by low, flat islands, *e. g.* the coast of the Western Taimur Peninsula (Pl. III, figs. 6—10)). It might, however, seem difficult to decide whether the low Siberian coast plains ought to be considered as a genuine coast platform, or rather as an ancient peneplain, the shallow valleys and depressions of which have been filled up by glacial drift and marine deposits; but according to the above theory the typical coast platforms, *e. g.* of Norway, have been formed by the conjoint action of marine denudation and atmospheric erosion, and in a low land like Siberia which has been submerged probably several times, it might therefore often be difficult to draw the line between a peneplain and a coast platform: during a period of gradual submergence the rounded low ridges of a peneplain will be cut down by the marine denudation, and the plain may thus be transformed more or less into a real coast platform. The west coast of Sweden, in Halland and Bohuslän, is perhaps an example of a land of this type. There is in this region a remarkable number of low, rounded ridges of Archæan rocks, which for instance in Halland, rise to very nearly the same level. The shallow valleys between the ridges are filled up by marine (and

alluvial) deposits, and also by glacial drift. When travelling with the coast railway through these districts, one can hardly help being struck by the extreme evenness and regularity of the land and its projecting ridges, its aspects of an ancient sea-level is altogether very impressive. I consider it possible that this is an ancient peneplain, which has been somewhat sculptured by glacial erosion, but which has also during periods of submergence, been more or less levelled by marine denudation cutting down the ridges. The shallow valleys were to a great extent filled up by marine deposits (yoldia clay) during and after the late glacial period, according to Prof. BRØGGER.

The depth at which the coast platform has been formed. Although ground-swell may break in very deep water, and boulders and shingle may be disturbed by waves at a depth of 20 m. or more and driven towards the shore, it cannot be doubted that the chief erosion of the waves reaches only to some few metres below the water-level. It has also been mentioned that the atmospheric erosion is a very important agent acting conjointly with marine denudation. We are therefore obliged to assume that at coast platform is during its formation, cut down only to some few metres below water-level. The outer submarine edge of the Norwegian coast platform may nevertheless have been eroded somewhat deeper by now through the action of ground-breakers during long periods. Some rocks, *e. g.* basalt, are corroded by sea-water, but the sea will hardly be able to lower its floor much in this manner within reasonable intervals of time.

The age of the Norwegian Coast Platform. Dr. REUSCH and Prof. VOGT have assumed that the Norwegian coast platform has been formed in pre-glacial times, although they do not consider that the possibility of its inter-glacial origin is entirely excluded. Prof. VOGT concludes it to be *Tertiary*,[1] but

[1] E. RICHTER concludes the Norwegian coast platform to be of interglacial age (*Sitz.ber. d. Akad. d. Wissensch. Wien*, 1896). Dr. ANDR. M. HANSEN ('Menneskeslægtens ælde', Christiania 1894—98, p. 345; *Arch. for Math. og Naturv.*, vol. 17, Christiania, 1895) believes that our coast platform has been formed during the latter part of the first glacial period (he calls it the protoglacial epoch) and he considers it possible, that it may have been chiefly formed by the scouring of the drifting ice. Although I consider it probable that there have been especially favourable conditions for the formation of coast platforms on a dissected coast, during glacial periods, I cannot agree with Dr. HANSEN that the scouring of the drifting ice can have been of much importance in this respect. Its effect cannot possibly be anything like that of the surf on a coast which is exposed to the full play of the open ocean.

his chief argument is that the platform must have been formed before the fjords, because it is absent in the inner parts of the latter. I have already mentioned (*ante* pp. 105—108) that, according to my view, this assumption is incorrect, and I cannot find any weighty reasons, why the Norwegian coast platform should be a pre-glacial formation; on the contrary, I think there are good reasons for assuming that it has been formed during the several glacial epochs, and I may especially point out here that:

1) The Norwegian coast platform is evidently a comparatively young formation, the greater part of which for instance, must have been formed after the Norwegian continental shelf, as will be mentioned later.

2) The fjords and sounds and submarine channels must have existed when the platform was formed, for the most part in practically their present shape, but as the fjords, etc., have been greatly sculptured during the glacial periods, the coast platform cannot be pre-glacial.

3) During, and after glacial periods there are especially favourable conditions for the formation of coast platforms, (as is mentioned on p. 109) if the coast has been sufficiently dissected beforehand.

4) It is a striking fact that the present sea-level has an intermediate position between the levels of the outer and the inner margin of the coast platform; the latter must consequently have been formed during small oscillations of the shoreline above and below present sea-level.

I believe that the history of the formation of the Norwegian coast platform may possibly have been as follows: at the beginning of several glacial periods the outer coast line of Norway may have stood very nearly at the same level as at present, or perhaps 20 or 30 m. higher.[1] During the early parts of these periods, while the glaciers gradually advanced into the inner fjords, especially favourable conditions for marine denudation prevailed on the outer coast, which was exposed to the attacks of a very stormy sea, not covered, at least not along the western and north-western coasts, by drifting ice. The climate on the coast was moist and cold; the rocks of the islands and promontories were splintered by the frost, and the fragments were gradually carried by running water and local glaciers into the sea, while the

[1] I do not here consider the possibility that at the beginning of the first glacial period and perhaps also later, the land may have stood considerably higher, perhaps 500 m. higher, than at present. I also consider it possible that Norway has had more than two glacial epochs.

wave-action vigorously attacked the base of the cliffs, and was probably assisted by the frost, which might be of importance at places where a great surface of the cliffs were constantly wetted by a great tide, as for instance was the case along the coast of Nordland.[1] Under the weight of the gradually accumulating ice, the land became slowly submerged, and the coast was subjected to marine denudation under the most favourable conditions. This submergence may, however, have been much checked — at times it may even have been transformed into an emergence — by the reduction of the volume of the ocean owing to the accumulation of a great quantity of water on the continents in the form of ice-sheets; on the other hand the submergence would have been slightly assisted by the attraction exerted by the great ice-caps on the sea-level. The submarine fjords and channels were gradually silted up by waste and glacial detritus; but this silting could hardly have been sufficient to have checked the marine denudation, before the inland-ice at last reached and covered the outer coast and interrupted the marine denudation; and then the fjords and sounds between the islands were again scoured by the glaciers, carrying all waste seawards with them.

When the margin of the inland-ice again retreated somewhat, from the outer coast, the fjords and channels would have been re-opened more or less, and deepened and widened, at the same time the waves got easier access to the inner islands; the waste was likewise carried away from the surface of the land, and fresh rock surfaces were exposed to the violent attacks of subaerial and marine denudation. According to my view, there may probably have been a great many oscillations of the margin of the inland ice, during which the outer coast was partly exposed and partly covered again by the ice, before, towards the later part of that special glacial epoch, the ice-margin finally retreated. If we assume that the pressure of the inland-ice caused a gradual submergence of the land, it seems possible that, when the ice-cap of a glacial epoch finally retreated from the outer coast, it might have stood much lower than at present; but there are, according to my view, several reasons for believing that this has not been the case. On the one hand, there is certainly a considerable 'lag' in all iso-

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[1] The frost may operate in two ways: 1) by directly desintegrating the rock, when it transforms the water into ice in the fissures. 2) loose material lying on the beach is embedded in the ice which is formed during low tide, and may be carried away with the ice when the tide again rises.

static movements of the earths crust; the depression of a coast such as this particular one would not have been appreciable until a long time had elapsed after the land was covered by the ice-cap, and it would have continued for some time after the ice retreated: on the other hand, during periods when the ice-caps retreated, water was gradually restored to the ocean whose volume would thus have been increased, and this would have immediately caused a rise of the sea-level, while the growing of the ice-caps had before caused a fall. Thus it is possible that when the ice-caps of the several glacial epochs retreated from the outer coast, the shore-line was relatively not much higher than it is at present, whilst the submergence of the coast may have continued for a long time afterwards. Prof. BRØGGER's investigations in the neighbourhood of the Christiania Fjord prove that such a submergence actually occurred in this region at the end of the last glacial period. When the margin of the inland-ice had retreated to the outer part of the Christiania Fjord, and the great moraines, or *ras*, of Moss etc. were formed, the sea stood only slightly higher than at present, while the greatest submergence of the region occurred during the time that the ice-margin had retreated to the lower end of the lake Mjøsen.[1]

During the gradual submergence of the coast after the ice-margin had retreated from the outer coast in the later parts of the several glacial epochs, the climate was still arctic or subarctic, and the atmospheric erosion consequently considerable — altogether very favourable conditions for the marine denudation of the freshly exposed rock surfaces on the much dissected outer coast. If there have only been two glacial periods in Norway the coast platform may have been especially formed during, and immediately after, the first glacial period, and at the beginning of, and during the later period. The latter assumption is not disproved by the fact that the surface of the platform is ice-worn, for the later glacial period may have lasted for a long time, and there may have been many oscillations of the margin of the inland-ice.

It has been mentioned that movements of the shore-line greatly favour the formation of the coast platform, because the surface exposed to the attacks of marine denudation is much increased. We know from the raised shore-lines along our fjords, that the coast has been considerably submerged

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[1] W. C. BRØGGER, *Norges Geologiske Undersøgelse*, No. 31, 1900, p. 683.

after it was ice-covered, and it may seem very probable that similar great movements of the shore-line have occurred during or after previous glacial periods; in spite of this, the coast platform does not rise above a certain level. The explanation of this fact is evidently as follows: — 1) the movements of the shore-line have not been so great near the outer coast line, as they were in the inner fjords,[1] thus the entire effect of the marine denudation, has there been concentrated within narrow limits, vertically. 2) It is only for comparatively short periods that the land was submerged to the levels of the highest shore-lines, and there was insuficient time for the formation of coast platforms at these levels. 3) During by far the greater part of both the periods of rising and of sinking, the shore-line has been very near to its present level; and this latter is most certainly nearly coincident with the mean level of the time when these oscillations were actually taking place; thus a coast platform was gradually formed near this level.

Prof. VOGT does not believe that the Norwegian coast platform can be a glacial phenomenon, or stand in any genetic relation to the ice ages, for according to his view, there is no coast platform on Greenland. The latter view is as we have seen, hardly quite correct (cf. *ante* p. 90, Pl.VI, figs. 2—4), since a coast platform evidently exists on the *west* coast of Greenland. It has also to be considered that the conditions for the formation of a coast platform are not very favourable in Greenland: the east coast is protected by drifting ice nearly the whole year, and has probably been so during all glacial periods, it has therefore, only insignificant indications of a coast platform; the west coast is washed by an enclosed sea, David Strait and Baffins Bay, which is also to a great extent covered by drifting ice. The apparent partial absence of a coast platform on the Greenland coast cannot therefore disprove our theory. It may, however, be more difficult to explain the absence of a typical coast platform on the Færoes, and its partial absence on Iceland.

As according to my theory, the coast platform has been formed to a great extent during vertical oscillations of the shore-line, it cannot possibly form a regular plane, but its level may differ much from place to place. But as

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[1] Cf. BRAVAIS; CHAMBERS; DE GEER; ANDR. M. HANSEN 'Strandlinjestudier', *Arch. f. Math. og Naturvid.*, vol. IX—X, 1890; AMUND HELLAND, 'Strandlinjernes Fald', *Norges geologiske Undersøgelse*, No. 28, Christiania, 1900, No. 2; J. REKSTAD and J. H. L. VOGT, *l. c.* No. 29, pp. 66, 150.

the lower limit of these shore-line oscillations, due to isostatic movements, is approximately dependent upon the equilibrium position of the land when not ice-covered, we must expect the lower level, of the coast platform to be much more sharply defined than its upper level. There may, therefore, be some difference of opinion as to where the coast platform has its inner boundary, whether at 30, 40, or 60 m. (VOGT, *ante* p. 52) or at 100 m. or even at 120 m. above sea-level (REUSCH, HANSEN, *ante* p. 52) and it may actually differ very much from place to place; but there is a good deal less difference of opinion concerning the level of the outer margin of the platform, which is only slightly below present sea-level. As the coast platform was largely formed during periods when the coast was more or less depressed by the weight of the inland-ice, it is natural that a great part of the platform should be now elevated somewhat above sea-level. There is still another circumstance which might have added to this effect: during the glacial periods a considerable load of waste was carried away from the land surface, and accordingly the land had to rise to a somewhat higher level in order to reach its equilibrium position, although it cannot have been much (see below), and besides, the effect of this movement was somewhat checked along the coasts, by the load of glacial drift deposited on the continental shelf.

The height of the level of the coast platform, depends somewhat on the geological structure of the rocks. It is obvious that islands and promontaries composed of weak rocks are cut back more and washed away sooner by the conjoint action of marine denudation and subaerial erosion, than are those composed of harder rocks, at the same time the wave-action will also erode the weaker rocks more deeply. It is therefore quite natural that by far the greater part of the Norwegian coast platform, near and above present sea-level, and especially the outer 'skjærgaard', is composed of Archæan rocks, as well as younger granites, gneisses, etc.; which possess a relatively high degree of resistance, we should in fact be much astonished to find skerries composed of weak rocks in the outer 'skjærgaard' exposed to the full play of the open sea. Where the coast platform, now elevated above sea-level, is cut in soft rocks — *e. g.* at Brønøsund where it is cut in limestone — it is as a rule protected against the open sea by a 'skjærgaard' of harder rocks. Where the outer coast, exposed to the full play of wave action, was originally composed of weak rocks before the formation of the coast

platform, it would naturally be much cut back, and would during the oscillations of the shoreline easily be worn down below the level of the latter's lowest position — even though this low position may have lasted for a relatively short time — and at such places there would consequently be no 'skjærgaard' present. This may perhaps to some extent explain the apparent absence of a 'skjærgaard' and a coast platform along the coasts of the Færoes and Iceland (see below) composed of basalts and other, still weaker, volcanic rocks, which are easily cut back by marine denudation and by subaerial erosion. This rule seems also to be con firmed along the Norvegian coast; the northern part of *Jæderen*, south of Stavanger, is composed of weak slates, there is no 'skjærgaard' outside, and the coast platform slopes seawards to a depth of between 50 and 60 m. (see Pl. XIX, Sections 37 and 37a). The islands *Karmø* and *Bokn*, north of the Bokn Fjord, are composed of similar slates; they belong to the coast platform, which however is low outside them (see Section 36, Pl. XIX) and has no 'skjærgaard', except the small island *Ulsire* which is composed of Archæan rocks (according to DAHLL's map).

The apparent absence of a coast platform and a 'skjærgaard' along the Finmarken coast, east of Sørø, may perhaps be explained in a similar manner. As is already mentioned (pp. 42—43), it is probable that the narrow shelf (5—12 kilometres broad) at depths of between 40 and 90 m. along the coast east of Sørø, corresponds to the coast platform farther west and south. This sudden change, at Sørø and North Cape, in the elsewhere fairly uniform level of the coast platform, coincides in such a striking manner with changes in the geological structure of the coast, that it cannot be a mere accident. It seems also a remarkable coincidence that off the coast east of Sørø the continental shelf is likewise much lower than it is farther south-west. The islands west and north of Tromsø: *Kvalø, Ringvasø, Rebbenesø,* and northern *Kvalø* (Pl. XIa, *K, Rin, R, N K*) are chiefly composed of granites and Archæan rocks,[1] and they have a remarkably well developed coast platform, with a 'skjærgaard' (10—20 kilometres broad), along their western coast. *Vannø* (Pl. XIa, *V*) has a more complex composition, across it there is a low

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[1] Cf. TELLEF DAHLL, Geologisk Kart over det Nordlige Norge, Christiania 1866—1879. Supplement to *Norges geologiske Undersøgelse*, No. 4, Christiania 1892. See also, A. HELLAND, 'Tromsø Amt', vol. I, 1899, pp. 41—43.

region with soft schists, perhaps belonging to the Cambrian system, and in its southern part there are slates belonging to the socalled Raipas system. Along the north-western coast of the island, composed of granites, though elsewhere imperfect there is a narrow but well developed coast platform. In the sea to the north there are, however, scattered traces of a coast platform which might seem to be a continuation of the coast platform off the islands to the west, and which is evidently cut in granite or Archæan rocks. *Fuglø, Loppen,* and the greater part of *Arnø* (Pl. XIa, *F, L, A*) are composed of relatively weak, possibly Cambrian rocks, and have no coast platform or 'skjærgaard' along their coasts, which are exposed to the open Loppen Sea, so much dreaded by tourists. The outer part of *Sørø* (Pl. XIa, *S*) is chiefly composed of weak Cambrian(?) rocks, only the north-westhern ends of some of its peninsulas are composed of Archæan rocks. Off its north-eastern part there are only a few islands and skerries — Store and Lille Kamø, Bondø, Bondø Skjær, etc. — composed of Archæan rocks, and on the south-west side of its western promontory composed of similar rocks, there is a narrow belt of skerries. But elsewhere the coast platform off this island lies relatively deep, generally between 40 and 80 m. (Pl. XII, No. 10), and at only few places does it rise to within 30 m. of the sea-surface. The explanation probably is that the coast platform is greatly composed of weak rocks like those of the island inside,[1] and these rocks have been much worn down during periods of the lowest position of the shore-line. An exception is Tubøen near the northern end of the platform (see Pl. XIa). *Ingø* (Pl. XIa, *I*) is composed of Archæan rocks and has a narrow coast platform with numerous skerries on its north and western side. *Hjelmsø* (Pl. XIa, *H*) is also according to DAHLL'S map composed of Archæan rocks, but has a but slightly developed coast platform. The northern side of the western peninsula of *Magerø* (Pl. XIa, *M*) is composed of Archæan rocks and has a well developed coast platform with skerries. The rest of Magerø is, with few exceptions —

[1] The geological structure of the region makes this very probable, we have here the northern prolongation of the Norwegian mountain system, with great mountain folds extending in a north-northeasterly direction. The Sørø coast platform lies exactly in the direction of the broad tract with weak, possibly Silurian and Cambrian schists, extending from Arnø toward SSW, inside Tromsø, Senjen and Vesteraalen. The Sørø Submarine Channel, west of Sørø is evidently a longitudinal fold valley carved in these weak rocks.

like the Finmarken coast farther east, as far as the Varanger Fjord — composed of sedimentary rocks, chiefly sandstones, quartzites, and clay-slates, belonging to the socalled Gaisa system; this coast is generally steep and shows cliff formation, and the narrow coast platform off the coast lies deep, between 30 and 80 m. below present sea-level. It is a noteworthy fact that, along the coasts of Magerø and the Nordkyn Peninsula, between Lakse Fjord and Tana Fjord, which are composed of older and harder rocks of the Gaisa system, chiefly quartzites, mica-schists and hard clay-slates, there are often near the coast skerries and shoals approaching present sea-level, whilst along the coasts of the Varanger Peninsula (between the Tana Fjord and the Varanger Fjord), which is composed of younger and weaker rocks of the Gaisa system, such are very rarely found; the coast platform has here evidently been cut down to a lower and more uniform level, in accordance with the smaller resistance of the rocks to marine denudation.

In the fjords of a land composed of relatively weak rocks, the marine denudation may in conjoint action with the subaerial erosion, be effective enough to cut a coast platform, but as the marine denudation is there less vigorous than on the open coast, it may not have been able to cut the platform down to the lowest position, which the shore-line might have had during a relatively short period, and thus the platform may there stand higher than on the outer coast. This may be the reason why, to judge from the charts, coast platforms near present sea-level, or a little above it, actually seem to occur in the inner ends of the open Finmarken fjords. I may especially mention the *Porsanger Fjord*, where there are numerous islands and skerries composed of rocks belonging to the Raipas system and possibly also to the Cambrian system.[1] It might, however, seem possible that the higher level of the coast platform in the inner fjords is due to the greater isostatic depression and subsequent upheaval of the land farther from the outer coast, but as was before pointed out, the coast platform was

[1] I have mentioned above (p. 108, footnote) that in the inner end of the Christiania Fjord, there are possibly indications of a coast platform. It seems possible that the soft Silurian rocks have offered the necessary conditions for the formation of a coast platform by the conjoint action of the subaerial erosion and the marine denudation, which has, however, always been very moderate in this enclosed fjord, although I have observed appreciable effects even of recent marine denudation at several places in the fjord.

hardly formed when the land was much depressed, and especially not in the inner ends of the fjords, which where first filled by glaciers, and in addition the level of the coast platform is everywhere remarkably uniform, and independent of the difference in the post-glacial elevation of the coast, as will be mentioned below.

If the above explanation be correct it might, however, seem somewhat difficult to understand why the submerged coast platform cut in soft rocks along the Finmarken coast, is so imperfectly developed: off Sørø it is from 9 to 22 kilometres broad, but even at the broadest places farther east its width varies only between 5 and 12 kilometres. Even the width off Sørø seems small if compared with that of the coast platform off the coast of Norland where it is on the average about 40 kilometres wide. But along the coasts of Lofoten, Vesteraalen and Senjen the coast platform is on the whole, very narrow — 7 or 8 kilometres broad. It is possible that the conditions have not been favourable for the formation of a coast platform on the steep and but slightly dissected Finmarken coast:

The wave-action may have been very moderate along the coasts of the relatively enclosed and shallow sea which may have been ice-covered to a much greater extent than at present during long periods, when the climate was colder. And besides it seems possible that the Vardø Channel and other submarine fjords may have been a comparatively long time filled by glaciers which on the one hand protected the coast against marine denudation, and on the other hand excavated the side slopes of the channels, and thus reduced the coast platform. It is a strange coincidence, that the coast platform is often comparatively narrow inside submarine fjords passing close along the coast: I may instance, the Vardø Channel; the submarine depression off North Cape; the great longitudinal submarine fjord along the coast between the Folden Fjord and the mouth of the Trondhjem Fjord; Bredsundsdybet off Stat; the Norwegian Channel along the southern coast of Norway.[1]

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[1] Dr. H. REUSCH has pointed out (*Det Norske geogr. Selskabs Aarbog*, vol. X, Christiania, 1900, p. 90), that the rocks belonging to the *Gaisa* and *Raipas* systems in Finmarken probably indicate the most western prolongation of the *Timan mountain system* extending from northern Russia over the Kanin Peninsula, Kildin, and the Rybachi Peninsula to Finmarken. It might seem possible that even the relatively recent vertical movements of the land have been different in the region of this mountain system from what they were in the region of the Norwegian mountain system, and as

The absence of a coast platform on parts of the southern Norwegian coast. It is a puzzling fact that there are only a few very imperfect traces of a submerged coast platform along the *southern coast of Norway*; especially is this the case *east of Lindesnes* (cf. p. 61). This coast is like the greater part of the Norwegian coast, chiefly composed of Archæan rocks, gneiss and granite, and the geological structure cannot therefore, explain the striking, imperfect development of the coast platform in this region. The explanation may be that: 1) The coast is comparatively little intersected by fjords and there have consequently not been conditions for the formation of a broad coast platform. 2) The marine denudation has been very slow on the coast of the enclosed Skagerak, and even on that of the North Sea, in comparison with what it has been on the coast farther north, exposed to the fury of the open Norwegian Sea; the wave action in the Skagerak has been trivial, the tides are comparatively insignificant, and the sea-currents are not very rapid. 3) The inland-ice may have reached the coast comparatively early in this region, where there were no deep fjords into which the ice could be discharged; thus the coast was during comparatively long periods protected against marine denudation. 4) The southern coast of Norway bounds the Norwegian Submarine Channel through which during each great glacial period, an enormous glacier certainly passed. This glacier had a great eroding effect; it scoured the sides of the channel, and may have more or less obliterated the coast platform previously formed. This obliteration has been most complete in the inner part of the channel, east of Lindesnes, where the erosion of the glacier has been greatest. It is a striking fact that nowhere along the coast south of the mouth of the Norwegian Channel,

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it very nearly coincides with the boundary between the two mountain systems at Magerø, this might give an explanation of the apparent disappearance of the coast platform in Finmarken, and this view would be supported by the fact that the continental shelf also lies lower off Finmarken, on the eastern side of this boundary line, than on its western side. Sørø belongs, however, to the Norwegian mountain system; its coast platform has nevertheless the same low level as the coast platform farther east, and this fact seems to disrpove the above explanation which on the whole is hardly well founded.

[1] The coast between Christiansand and the Christiania Fjord is low, and the land rises inland, on the whole gradually, (see Sections 40—41) so that it may be difficult to distinguish the coast platform (cf. REUSCH *l. c.* p. 3). The land surface is generally rugged and compared of innumerable small rounded ridges, which still, at many places, seem to have a fairly uniform definite level. In the 'skjærgaard' I have perhaps observed two lower levels, *e. g.* south of Risør, one just at present sea-level, and another a little higher.

is the coast platform so well developed as it is farther north; the continental shelf is also wanting along the side-slope of the Norwegian Channel (*ante* p. 60).
5) During long periods before and after each glacial epoch, the Skagerak has probably been covered with sea-ice protecting the coast against wave action; along the Norwegian west coast bounding the North Sea there has also during long periods, probably been a cold current carrying drifting ice from the Skagerak and the Baltic, and thus this coast has also been much protected.

According to my observations, *the scouring of the drifting ice on the cliffs of the outer coast* of an arctic land, has but little eroding effect compared with that of the wave action; and as there is practically no surf on a coast inside a belt of drifting ice, this latter will protect the coast against marine denudation rather more than it will erode it. The drifting ice may certainly carry blocks and boulders, but this transportation is performed chiefly by the so-called "ice-foot", which has to be distinguished from the drifting ice, as it is a formation which may also occur on relatively open coasts where there is little drifting floe-ice, and where the "ice-foot" may often be broken loose by the heavy surge. During ice-pressures the floe-ice may often have an opposite effect, as it carries boulders and cobbles towards the shore and aids in the formation of a beach. I have also observed that on coasts which during the greater part of the year are protected by drifting ice, the "ice-foot" is not broken loose by the surf, but may during the summer have time to melt away quietly, *in situ*. The Sections 35—41 make it probable that there was never a broad coast platform along the southern coasts of Norway; for the slope indicated by the heights of the mountains inland, descends quite gradually towards the coast, and in Sections 38—41 (Pl. XX) there is only a small horizontal incision near the shore-line, between this slope and the inner submarine side-slope of the Norwegian channel; in the sections farther north, Nos. 35—37 (Pl. XIX), the incision is somewhat greater.

The great width of the coast platform along the coast of Nordland, between 64° 40′ and 67° N. Lat., is probably due to the geological structure, which in this region is rather complicated and very different from what it is in the Søndmør, Romsdalen, Trondhjem region, composed of Archæan rocks, and in the Lofoten-Vesteraalen with its composition of Archæan roks and gabbros. Nordland is a much folded region where the sedimentary rocks — prob-

ably Silurian and Cambrian — have at many places been lowered below present sea-level. These rocks were easily cut back by marine denudation and subaerial erosion, leaving behind exposed islands, composed of harder rocks — granites, gneiss, gabbro, etc. — but as these islands were as a rule not very high, they were to a great extent also gradually worn down to sea-level. Thus the coast platform became much broader in this region than north and south of it, where the coast mountains were higher and steeper, and on the whole composed of more uniformly hard rocks. According to Prof. VOGT the mean slope indicated by the mountain peaks (see below) is in the Romsdalen region about 1°, while in Helgeland it is only 40′.

The absence of a typical broad coast platform on the Færoes. The aspect of the often nearly vertical cliffs along the outer coast of the Færoes proves that they must have been exposed to a very great marine denudation; there must also have been very favourable conditions for such a denudation on these weather-beaten islands: the wave action is violent on all sides, the tidal currents as well as the oceanic and the wind currents are very rapid, and all waste is easily washed away into deeper waters. The coasts have evidently also been much dissected by fjords and sounds; nevertheless there is practically no 'skjærgaard'. The explanation is probably that the volcanic rocks possess much less power of resistance to marine denudation than the foundation rocks of the Norwegian coast, and just as we assumed above in the case of the Finmarken coast, the coast platform has consequently been easily cut down below the lowest previous position of the shore-line, leaving very few or no protuberant parts. If we can assume that the Færoes have quite recently been much submerged, and that during the glacial periods when the Norwegian coast platform was formed, the shore-line there stood much lower (*e. g.* 60 or 80 m.) this would obviously give the most natural explanation, and this again is strengthened by the interesting fact that no raised beaches or other evidences of a post-glacial upheaval of the land have then been observed; all caves occur at present sea-level, while in Norway they are much elevated. It seems therefore to be certain that the Færoes have at least not risen recently; they may have been submerged. There are, however, the difficulties — on the one hand that there is no distinct difference between the thus submerged coast platform and the continental shelf, — and on the other hand the continental shelf

of the Færoes is evidently the same formation as the Norwegian and the British continental shelves, and lies at very similar depths, both of which facts might seem difficult to explain if the land has been recently submerged as much as 60 or 80 m. It might however, be possible, that during the glacial periods the sea-level stood rather lower on the Færoes than in Norway. It is for instance probable, that the volume of the ocean was reduced by the formation of the great ice-sheets; how much the sea-level sank in this manner cannot be computed; but it may have been appreciable if we assume that the European, American, Siberian, and perhaps also the Antarctic ice ages were simultaneous. The fall of sea-level was in Norway apparently much checked by the isostatic movements of the land due to the pressure of the great ice-caps. On the Færoes these isostatic movements may not have been very great, as the ice-cap cannot have been very thick; thus the total result may have been that the fall of sea-level caused a considerable lowering of the shore-line on its coasts. There is still another possibility: if we assume that the Scandinavian British platform has actually been depressed by the weight of the inland ice during its greatest extension, we must also assume that at the same time there has been an isostatic movement of the bottom of the Norwegian sea in the opposite direction, and thus may the ridge on which the Færoes are situated have been actually raised.

The absence of a typical broad coast platform on the wheather-beaten Orkneys and the Shetland Islands is also interesting. It was above (p. 96) pointed out that a narrow coast platform with numerous skerries and shoals probably extends along the western coast of Scotland and the Hebrides, this regions is chiefly composed of Archæan gneiss, whilst the Orkneys and Shetland are chiefly built of younger and weaker sedimentary rocks; we see again that the coast platform with 'skjærgaard' is chiefly limited to the Archæan region. The nature of the coast of Shetland and also of the Orkneys is very instructive. It is evident that on the open western coasts of the islands, where the marine denudation has been most effective, the rocks of the coast platform have been worn down below the lowest former position of the shore-line, and therefore the sea is relatively deep along the open western shores, and there are very few skerries and sunken rocks. But in the sounds between the islands, and to some extent also on their eastern coasts, the marine denudation has been less effective, and has not been able to wear the rocks of

the coast platform down to the same low levels as on the western coasts, and therefore, many skerries, shoals, and small islands still remain near present sea-level.

The partial absence of a coast platform on Iceland may have a similar explanation: its weak volcanic rocks have easily been cut down below the lowest previous position of the shore-line, leaving no or a very imperfect 'skjærgaard'. But as Iceland probably has had a much thicker inland-ice than have the Færoes, its isostatic movements have probably also been greater; there are actually numerous evidences of post-glacial elevations of the coast.[1] The following points ought also to be taken into consideration: 1) great parts of the Icelandic coasts are modern formations; 2) the Icelandic coasts have not been so much dissected as the Norwegian coasts; 3) along the south coast of Iceland for instance, the modern alluvial and marine plains may cover an older coast platform. 4) During comparatively great parts of the glacial periods the inland-ice may probably have reached the outer coasts and may have protected them against marine denudation.

We have seen that at several places there are formations which much resemble a typical coast platform, *e. g.* in the inner parts of Breidi Fjord and Faxa Fjord. According to my view, it does not seem a natural explanation to say that these extensive lowlands are simply the surface of basaltic plateaus which have happened to have been lowered by trough faults exactly to the very level at which we might expect to find a coast platform, all the while retaining very nearly their original horizontal situation over such great distances (nearly 150 kilometres from Reykjavik to Bardastránd). Dr. THORODDSEN's investigations seem to prove that the regions of Breidi Fjord and Faxa Fjord have been lowered by great dislocations; but according to my view, it seems probable that the surface of these lowlands or coast platforms, must have been levelled by marine denudation.[2] It might be objected that if so, it is

[1] Cf. TH. THORODDSEN, *Geografisk Tidsskrift,* vol. XI, Copenhagen 1892, p. 209.

[2] Just as this is going to press I find in the last number of *Geografisk Tidsskrift* (vol. XVII, Copenhagen, 1903, p. 32) a paper by Dr. THORODDSEN in which he states that the tiers of basalt building up the lowland (Myrar) of the Faxa Fjord "dip several degrees landwards". This seems to strengthen the above view, for as the level surface of the lowland has evidently no similar slope, the plain must cut the tiers of basalt, and cannot be the original surface of the basaltic plateau. It must consequently have

strange that the neighbouring regions of Reykjanes, Snæfellsnes, and the great north-western peninsula have not been more altered by a similar marine denudation; but the coasts of Reykjanes and Snæfellsnes have evidently been much altered by modern lava streams etc.; and along the coasts of the north-western peninsula it is doubtful whether a submerged coast platform does not actually exist at depths of between 20 and 40 m. We cannot be astonished to find the coast platform at slightly different levels along the coasts of Iceland, where volcanic forces are constantly at work; and besides, I have pointed out above in the case of the Finmarken fjords, that in the inner part of fjords with shores composed of weak rocks, a coast platform may probably be formed, but its level will be higher than on a more open coast, because the less vigorous wave-action may not be able to cut the platform down below the lowest temporary position of the shore-line. The Icelandic coast platform has not yet been subject to systematic investigations, and little can be said about it at present, but it seems probable that future investigations might bring many important facts from this interesting island.

Coast Platform ("Strandfladen") and *Raised Shore-Ledges ("Strand-linjer")*[1]. It is, according to my view, hardly correct to say that there is in general a distinct natural difference between these two structures, it may often be difficult to draw the line between them. The raised shore-ledges forming notches in the rocks, have been cut by marine denudation (wave-action, frost, ice, tide) during pauses in the vertical oscillations of the shore-line, while the coast platform is the final result of the conjoint action of marine denudation and subaerial erosion for long periods during wich there may have been many oscillations of the shore-line above and below a mean position. We may consequently, as a rule, expect to find several different, more or less distinct, levels in a coast platform, and several shore-ledges may actually form parts of it, although they may be difficult to trace out. The

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been cut by denudation of some kind, and if so, it seems natural to assume that this has been marine denudation. If this denudation has been considerable, the underlying land might possibly have risen by isostatic movement, and thus a slight landward dip of the tiers of basalt, although not as much as several degrees, might be explained.

[1] I prefer here the expression *shore-ledge* to *shore-line*, as we use the latter expression simply of the line where land and sea meet, whether it is incised or not. I do not here consider *raised beaches* and *terraces*, as they are chiefly built up of loose materials, and are of minor importance in the formation of a coast platform.

formations of the shore-ledges are thus, to some extent, steps in the formation of the great coast platform. But the shore-ledges may be formed somewhat differently and may get different shapes according to the local conditions: *On the outer coasts* exposed to the full play of the open sea, the violent wave-action is the predominant agency in the formation of the shore-ledge, which accordingly will become comparatively broad but form no very regular and sharply defined notch in the rock, because the waves erode at different depths according to their size, and will round off the rocks above and below the mean level of their attack. If, therefore, the shore-line does not remain stationary for a very long period, the incisions thus formed, will not be very conspicuous, and may easily be overlooked. In *the sounds and outer part of the fjords,* the wave-action is less effective, and the other agencies are comparatively more important: the erosion by the frost on the rocks wetted by the tides, the "ice-foot", and perhaps to some small extent also the transport and scouring of the drifting ice carried by wind and tidal currents. The effects of these agencies is limited to the actual water-level, and, as if cut by a file, a sharply defined rock notch is formed, which cannot easily escape observation. This is probably the reason why the raised shore-ledges are chiefly observed in the sounds and outer part of the fjords of northern Norway and so very seldom on the outer coast, where, however, they actually may be found at several places. On the several sides of *Torghatten* there are distinct incisions and small plains of marine denudation marking the position of the shore-line during the greatest late glacial or post-glacial submergence, to about 110—130 m. above present sea-level (see Pl. V, fig. 4); the hole through the mountain as well as several other hollows and caves (see fig. 4) are very nearly in the same level and was evidently formed by wave-action during the same period[1]. During the above period of greatest submergence Torghatten formed an isolated island in the open sea, and it is interesting to notice that the incision in the mountain-side is situated lowest and its floor is most sloping on the outer side (the left hand side in the picture) which was exposed to the most vigorous attacks of the wave-action[2]. On the whole

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[1] Cf. J. REKSTAD and J. H. L. VOGT, *Norges geologiske Undersøgelse*, No. 29, 1900, p. 100.

[2] The great dimensions of the denudation at this ancient sea-level is clearly demonstrated on Dr. REUSCH's sketch of the island seen from the north (*l. c.* p. 9). REUSCH considers this higher platform, at a height of somewhat more than 100 m., simply as a part of the coast platform, which "is here disolved into two levels or two coast platforms".

the floor of these incisions are more sloping than the floor of the much narrower raised shore-ledges in the sounds and fjords. On the sides of *Lovunen*, lying still farther out to sea, there are similar incisions (Pl. V, fig 1); they were possibly also formed by marine denudation[1]. If the shore-line had remained near this position during sufficiently long periods the upper parts of the islands along the coast would gradually have been eroded down to this level, and a corresponding coast platform might have been formed, it would in fact depend on the extension of the erosion whether we would find this expression appropriate. On the outer, open side of Kamenni Island off the Siberian coast, facing the Polar Sea, I have also observed raised shore-ledges (Pl. III, fig. 11).

In Norway there is a distinct difference as to time of origin, between the ordinary raised shore-ledges, which are post-glacial and not ice-worn, and the coast platform, which is older.

Cause of the post-glacial movements of the shore-line indicated by the raised shore-ledges. It is a very remarkable fact, that, although the maximum height of the post-glacial movement of the shore-line, marked by the raised shore-ledges and the upper marine boundary, differs much — often more than 50 m. — along the outer Norwegian coast-line[2], still the coast platform is on the whole, practically at a uniform level, at least its lower edge. As the coast platform has been formed before the raised glacial or post-glacial shore-ledges this fact proves that the *outer coast must have been unequally depressed in different regions during glacial times, and has again risen to very nearly its original level;* the post-glacial elevation cannot therefore, to any great extent, be due to unloading of waste by the denudation of the land surface during the ice age. On the other hand it also proves that the coast platform must have been formed so late that the subsequent denudation of the land has not been able to change its equilibrium position to any appreciable extent. The above fact is a strong evidence that the glacial depression

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[1] To judge from the photograph, these incisions stand probably nearly 280 m. above sea-level (the greatest heigt of Lovunen is 619 m.), and much higher than those of Torghatten. If they actually indicate an ancient shore-line they must originate from the former glacial period when the inland-ice had its greatest dimensions.

[2] The maximum vertical movement of the post-glacial shore-line, above present sea-level, is on the outer coast between Sogne Fjord and Søndmør 50 m. or less (*e. g.* at Bremanger and Stat), in Lofoten, Vesteraalen and Senjen between 10 and 50 m., while on the outer coast of Helgeland it is about 100 m.

and the post-glacial elevation of the coast has actually been due to the weight of the ice-sheet, as has been assumed by JAMIESON, ANDR. M. HANSEN[1] and others. It is worthy of mention in this connection, that, while in Norway there is apparently no relation between the post-glacial elevation indicated by the raised shore-ledges, and the level of the coast platform, still the apparent absence of raised shore-ledges and a post-glacial elevation on the Færoes (as well as on the Orkneys and Shetland, see Postscript below) coincides with the absence of a coast platform, as is mentioned above (p. 123).

Postscript. After the preceding pages had gone to press Sir JOHN MURRAY sent me a letter from Dr. B. N. PEACH. As it contains information having an important bearing upon some of the above questions, about which I had previously written to Sir John, I am glad to have the opportunity, very kindly allowed me, of reproducing it here.

Letter from Dr. B. N. PEACH, *F. R. S., of Scottish Geological Survey, to Sir* JOHN MURRAY.

Geological Survey Office, Edinburgh, 23rd May, 1903.

My dear Sir John.

Yours of yesterday enclosing letter from Dr. Nansen to hand. Dr. Nansen is quite right about our Raised Beaches or "Strandflade" on both sides of Scotland. Our highest raised beach is the "hundred feet beach", the upper limit of which is in a general way about 100 feet above ordnance datum line; but it runs up above that line as we proceed inland along the sea-locks and estuaries and goes below that line as we pass outwards towards the open coasts and islands. It may be either a rock notch unaccompanied by beach material on the exposed shores, or it may be in part beach and partly made up of old sea bottom deposits like the Portobello clays. When any fossils are found in this deposit they are always of a higly arctic type, and it is in these deposits that the clyde "Arctic Shell Bed" occurs. This beach occurs at the mouth of Lochs *Carron* and *Torridon*, in Rosshire, but further up these lochs its place is occupied by morraines showing that glaciers extended down to sea-level in these sea-lochs or fjords during the deposition of the "hundred feet" beach.

The next beach is the "fifty feet" one. This marks a long pause in the upheaval process, shown both by the great notch planed out by the sea at this level, and also marked by the fossil contents of the beach material being the remains of the shells and other animals that are now extant on our shores. It is at the edge of this raised-beach that the great Kitchen Middens are found, and in it the remains of stranded whales are found side by side with old canoes and implements like harpoons, and in the case of the Gargunnock whale there was an implement sticking in the skull of a whale at a place where the bone is thinnest[2]. It is this beach which in the western islands is always below 50 feet — often about 35 feet

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[1] ANDR. M. HANSEN, *l. c.*, 1890, and 'Skandinaviens Stigning', *Norges geologiske Undersøgelse,* No. 28, 1900, pp. 78 *et seq.*.

[2] These direct evidences that the land has been elevated so much as late as after its population in postglacial times are of much importance; Dr. ANDR. M. HANSEN is preparing a paper in which he will bring forward evidence that the first population of Norway also probably took place before the last elevation of its coasts. F. N.

above ordnance datum line — that is accompanied by the old cliff with its sea hollowed caves which is so conspicuous a feature on the coasts of Scotland. — Between this and the present sea-level there are several terraces along different parts of the coast, but the most marked one is what is called the "twenty five feet beach" which evidently marks a longer pause between oscillations than the others. On the west coast it seldom reaches the 25 feet level and may be only 15—20 feet or even lower.

The buried peat bed ("Forest Bed"), shown in Mr. Henry Coat's section that we saw at Perth as extending under some of the "Carse" beds, clearly indicates that there must have been sinking as well as elevatory movements during this period, for the forest bed is covered by "carse" clays containing the remains of a marine fauna. From what I have said, there seems to be some evidence as to the warping of the land, even where the movements have been, on the whole, those of elevation. Horne and I have found, however, that north of a line drawn obliquely across Caithness from NW to SE the evidence is everywhere in favour of depression. In the first case the negative evidence of entire absence of raised beaches favours that opinion, while, on the shores of Sinclairs Bay in Caithness we have peatmosses passing out to sea beneath the sandy beach. After storms the old tree stools are seen standing in place in this moss. In Lybster Harbour, about 12 miles south of Wick, also in Caithness, there is a deposit of peat *in situ*. In deepening Wick Harbour, fresh-water shell marl was dug out between tide marks, and nearer low than high tide mark. This fact was pointed out to us by Mr. Charles Johnstone of Wick. Great masses of peat are torn up by the tide and storms in the channel between N. Ronaldshay and Sanday in Orkney; and this deposit was seen and described to us both by the late Dr. Traill of Woodwick, N. Ronaldshay, and my father. Some of the Shetland voes are floored by peat below the recent muds, and the peat is often brought up on anchor flukes. The absence of raised beaches in Shetland and Orkney is very significant as spits and banks are very conspicuous structures along the present sea margin showing that the materials and the agencies are there to produce beaches. — — — — — — — — — — — — —

Yours etc.

BEN. N. PEACH.

These interesting observations seem to support the above views. Scotland has been elevated more inland than near the outer coasts; and in its northern part as well as on the Orkneys and Shetland the coast has been submerged to some extent. It is important that during the periods when the Scotsh raised beaches, and probably also the Norwegian coast platform, were formed, the movements of the shore-line have differed to this extent in Scotland and on the islands to the north (as well as on the Færoes, see p. 123). If we assume that these movements of the shore-line have been due to isostacy, the upheaval must naturally have been greatest in the inner parts of Scotland, where the ice-sheet was thickest, while on the Orkneys and Shetland the ice-sheet were always relatively thin and probably excisted for much shorter periods. When Scotland was depressed by the weight of the ice-sheet, it is therefore possible that the platform on which the islands lie, was even slightly lifted, and besides, the shore-line was probably lowered by the reduction of the volume of the ocean. Thus it is possible that the islands were actually somewhat submerged in post-glacial times. The continental shelf round them was moreover loaded by waste, which circumstance may have slightly increased the post-glacial depression. If the above view be correct the coast platform of the open coasts must clearly have been cut down to a relatively lower level during the glacial period on these island groups, and this level may coincide more or less with that of the continental shelf, so that the one structure can hardly be distinguished from the other.

HOW MAY CONTINENTAL SHELVES BE FORMED?

Although there is much resemblance between the coast platforms and the continental shelves, it is a much more complicated affair to find out the origin of the latter. It would be very simple if we could assume that the continental shelves were originally coast platforms which have been submerged and filled up more or less to form undissected or gently rolling submarine plains. But this theory accepted as a general explanation, will at once give rise to serious difficulties. Leaving out of account the fact that the continental shelves are often standing at different levels in neighbouring regions where the physical conditions may be different, it cannot but strike one, that the continental shelves occur in almost all parts of the ocean from the coasts of the North Polar Basin and the North Atlantic to the coasts of Patagonia and Australia and probably even in the Antarctic. The above theory would then mean that there has been a general submergence of all these coasts; and as nearly all continental shelves stand at levels between 50 and 200 m. this submergence must have been remarkably uniform, and can hardly have been due to simultaneous epeirogenic movements of the lithosphere, but must have been due to a general and comparatively uniform rise of the sea-level. But even if we assume that such a comparatively small rise of sea-level might have been effected by an increase of the volume of the ocean, or by a rise of the sea-bottom by deposition of sediments[1], the drowened river valleys descending to great depths offer a new and serious difficulty, as some of them at least, have obviously been formed or re-opened after the continental shelves were formed; all this would then indicate great vertical oscillations of sea-level over the whole globe, which must have been caused by remarkable oscillations of the hydrosphere or by rise and fall of the sea-bottom. Before accepting a theory with such wide-reaching consequences, we ought to look round for other explanations, especially should we examine whether it is not possible to assume that the continental shelves may have been formed at the present sea-level.

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[1] This theory involves the difficulty that the greater part of the terrigenous waste is deposited near the coasts, and this would raise the floor of the continental shelves more than the sea-level.

As far as I can see there are chiefly four methods[1] in which continental shelves may be formed in northern seas: 1) They may, as mentioned above, be *submerged coast platforms* cut by the conjoint action of marine denudation and subaerial erosion. 2) They may be *submerged continental plains* or *peneplains*. 3) They may be built op by *sea deposits*. 4) They may be built up by *glacial drift*.

(1.) *Submerged Coast Platforms.*

I have mentioned this method of formation above and it is innecessary to repeat it here; but as the continental shelf is probably to the greater extent, a pre-glacial structure, the formation of its eventual, now submerged coast platform must have required much longer time than that of the present Norwegian coast platform, which was probably formed during the favourable conditions of the glacial epochs. If a broad coast platform cut along an originally much dissected coast — *e. g.* the coast platform of Nordland, Norway — be submerged to a depth of 100 or 150 m. or more, its fjords and sounds would soon be more or less filled up with marine sediments, its surface would thus gradually be levelled a good deal, and would become very similar to that of the present continental shelf off the same coast.

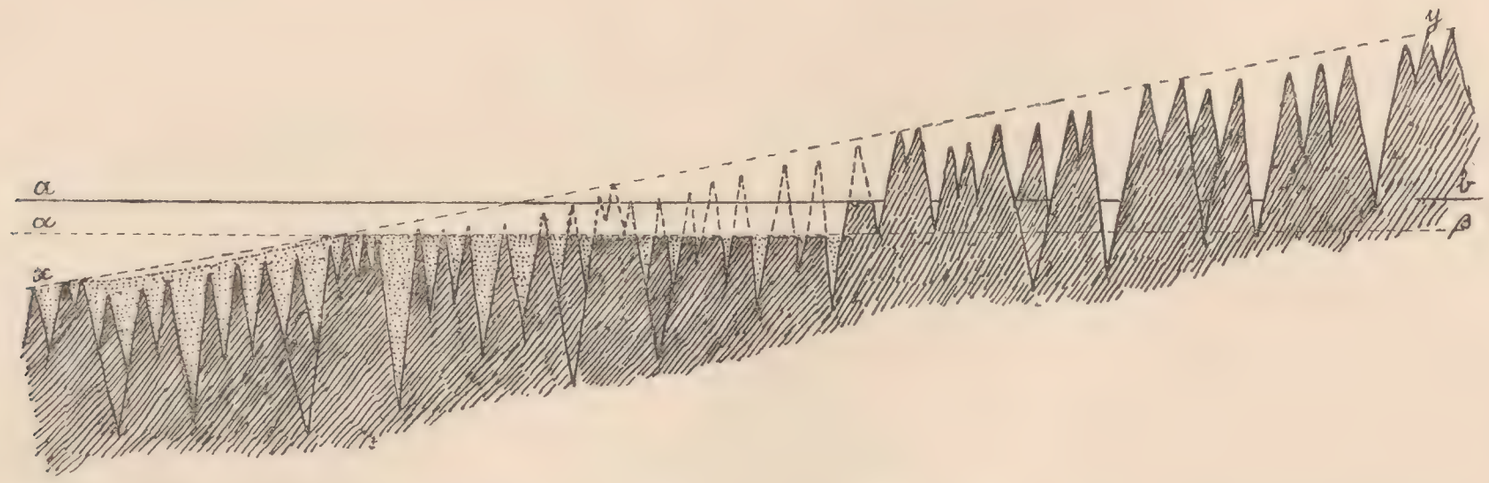

Fig. 1 *ab*, Present sea-level. *αβ*, Mean ancient sea-level. *xy*, Ancient land-slope.

The characteristic features of a continental shelf formed exclusively in this manner along a submerged coast, having a uniform general slope above and below sea-level, would be that the shelf forms a distinct horizontal incisions in the original slope (fig. 1, *xy*), indicated by the land slope and the

[1] In warm seas continental shelves may be formed by corals and other organisms, but this mode of formation may here be left out of concideration as it is of local importance.

submarine continental slope — the one in fact, a continuation of the other, with no abrupt change of inclination between them. In the earlier stages of the shelf's history, it may have had a fairly uneven surface, where the protuberant parts rise approximately to a uniform level, while in a state of maturity it would form a gently rolling plain where, however, slight depressions might still indicate the position of the ancient channels. It ought to be observed, that according to what has been said above (p. 116), the thus formed continental shelf may be expected to lie lower where the coast was composed of weak rocks, than where the rocks offered more resistance to marine denudation.

I believe that continental shelves actually have been formed to some extent in this manner, some parts for example, of the Norwegian as well as the Icelandic continental shelf; but it can hardly be accepted as a general explanation of all continental shelves whether broad or narrow. It would mean that all coasts have been much dissected and have been submerged before the shelves were formed.

As I have pointed out before (p. 105) I consider it an impossibility that a submarine level plain with such an insignificant slope as the typical platform or the continental shelf, can be cut by marine denudation on undissected or only slightly dissected coasts; if Richthofens' "Abrasionfläche" or plain of marine denudation was ever formed along undissected continental coasts, it must necessarily have had a much steeper slope than the continental shelves we know. I doubt much that they ever were formed to any great extent[1].

(2.) *Submerged Continental Plains or Peneplains.*

If a continent remain sufficiently long at a fixed level, it is gradually worn down towards its base-level of erosion, and its surface will approach this level and form a peneplain. This stage of maturity will first be reached near the coasts, where the land surface will then be only slightly above sea-level, whilst there may still be higher mountains farther inland. The continental slope which is below sea-level and below the reach of marine denuda-

[1] Some recent authors seem to take it for granted that the continental shelves have simply been cut by marine denudation, but I have seen no clear description of the assumed process; it is also often unclear whether they assume the denudation to have taken place at present sea-level, or at an earlier lower sea-level.

tion will not be eroded and will remain unaltered except for the deposition of sediments on its surface. Even though the slope of the continent may originally have been uniform, in one sweep, from its highest part towards the floor of the ocean (fig. 2, *xy*), an abrupt break in this slope would thus gradually be formed in the course of time (fig. 2, *c*). If the coasts of such a continent be somewhat submerged, the low coast land will form a continental shelf, which may become very level when its shallow valleys are filled up with marine deposits.

The characteristic features of a continental shelf of this type which has not been modified by other agencies[1] will be an often broad and gently rolling or even nearly level plain, which gradually rises above the sea and is continuous with the peneplain or the mountain slope of the land inside (fig. 2), without any abrupt incision. The continental slope outside the shelf may be comparatively steep and is much steeper than the slope of the land whitin, of which it forms no continuation. If there has been time for the marine denudation to cut back the shores after the submergence, there might naturally be a more abrupt step between the continental shelf and the land slope within. Deposition of waste may naturally, also much modify the aspect of the shelf.

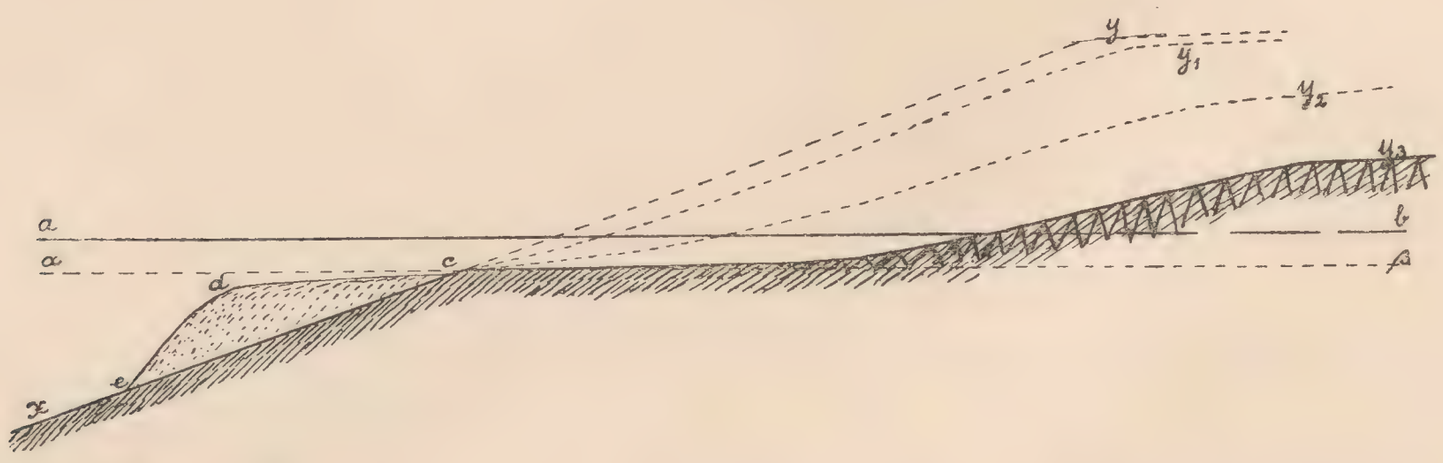

Fig. 2 *ab*, Present sea-level. *αβ*, Ancient sea-level. *xy*, Original land-slope. cy_1, cy_2, cy_3, Land-slope at different stages of denudation. *cde*, Shelf formed by waste.

It is evident that this mode of formation must have been of some importance during the history of the continental shelves of all old continents, even though there may have been great oscillations of the shore-line. We

[1] This condition will hardly ever occur in nature, for the greater part of the enormous quantities of waste carried into the sea during the denudation of the continent, will be deposited on the sea-bottom outside the coast (fig. 2, *cde*), and will add to the formation of the shelf.

know that all such continents which were originally much elevated above the sea, have been denuded thousands of feet or thousands of metres, while the sufficiently submerged parts were not eroded; this circumstance must in the course of time tend towards the formation of a comparatively level platform or semi-plain, near the mean position of the shore-line oscillations. It does not seem impossible for instance, that the Siberian continental shelf as also the drowned plain of the Barents Murman Sea might have been formed to a great extent in this manner; on the other hand the continental shelves of the Færoes and Iceland cannot have been formed in this way, furthermore the present surface of the inner part of the Norwegian continental shelf, which forms a deep horizontal incision in the land slope, cannot have been thus formed.

But both the above theories imply that there has lately after the continental shelves were formed been a comparatively uniform submergence; the following explanation is not open to this objection.

(3.) *The Formation of Continental Shelves by Sea Deposits.*

The greater part of the terrigenous waste, formed by subaerial erosion (and carried by streams and glaciers) and by marine denudation, is constantly being deposited on the sea bottom as near the coast as the depth and the movements of the water, allow. In the course of time continental shelves must be built up in this manner. The depth below sea-level to which they may thus he built up will depend on the depth to which the sea off the coast is sufficiently moved by waves, tides, and currents to disturb or transport the waste: on the coast of an enclosed sea the continental shelf will grow in this way to a much shallower depth than on an open coast exposed to the full play of a great ocean, where the great waves and strong tides and currents will "scour" to great depths. We know, for instance, that in the upper parts of the narrow fjords of Greenland and Norway the sea has been silted up above present low water level; we should naturally consider it impossible that such a thing could happen on an open coast. By the motion of the water on the bottom, the course grains may be constantly worn smaller, all fine waste will gradually be washed farther and farther seawards into deeper and deeper water, until finally the motion of the water is no more sufficient to move the particles. The limits of this depth may depend on the size and

weight of the grains and on the movements of the water due to waves and currents.

The vertical distribution of wave movements. There are unfortunately very few and imperfect direct observations of the depth to which wave motion may be practically effective in this way; but they seem to coindicate that, on the coasts of the open ocean, the bottom deposits may be disturbed at least to depths of 150 or 200 m.

Observations on the sea-surface, breakers. We know that the great waves coming from a deep ocean and suddenly entering the shallow sea over a continental shelf or over an oceanic bank may break in very deep water. Ground-swell breaking in 30 or perhaps even 40 m. water is not uncommon off the Norwegian coast. CIALDI states that waves may break in 46—57 m. water off Punta Robanal in northern Spain, and in 84 m. on the Syrian coast[1]. STEVENSON mentions breakers in depths of at least 70 m. near Fair Island[2], where, however, the tidal currents are very rapid, and may well produce breakers when they meet the wind. AIRY states, that on the edge of the continental shelf at the entrance to the English Channel breakers may even occur in 180 or 200 m. water[3]. Not having seen AIRY's paper I do not know on what foundation this startling statement is based, but it seems to me very doubtful, and I have not seen it confirmed by any later observations. It is obvious that where ground-swell breaks owing to the shallowness of the sea, the oscillatory wave motion must be considerable at the sea-bottom, and may be well able to disturb the bottom deposits.

If Capt. TIZARD be right when he asserts that he has found the sea more choppy over the Wyville Thomson Ridge than on each side[4], and if this be caused by the shallower water, it would seem to imply that the movements of the water must have been appreciable right down to the surface of the ridge, which lies at a depth of between 320 and 576 m. It is, however, very probable that it is the tide or the currents coming from the deep ocean and meeting the obstacle of the ridge, which is accelerated or forced upwards to such an extent that it affects the surface. Sir W. WHARTON also mentions, in a letter to me, that he "had an interesting case in the Coral Sea where a ship had reported breakers. When looked for, a bank of 800 fathoms (1463 m.), was found, in nearly 2000 fathoms general depth, but there were distinct tide rips over it, which at a little distance in the sun light looked like, and were reported as breakers. It was clearly the tide at the bottom which meeting this large mound and becoming accelerated, ran up the face of the mound and took the line of least resistance to the surface". And he thinks "that this acceleration of the tide when meeting — — — slopes has much to say to the moving and therefore distributing down hill, of the lighter material on the bottom, though doubtless the motion caused by surface wind waves also plays a large part". It appears to me that whatever it is — tides or waves — the sea surface cannot be affected in this manner unless the movement of the water is also appreciable at the sea-bottom on the banks, ridges, and continental shelves.

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[1] CIALDI, 'Sul moto ondoso del mare', 2nd edition, Rome, 1866, § 580, 589; quoted by KRÜMMEL, 'Handbuch der Oceanographie', vol. II, p. 90.

[2] THOMAS STEVENSON, 'Design and Construction of Harbours', 2nd ed., Edinburgh, 1874, p. 62; quoted by KRÜMMEL *op. cit.* p. 90.

[3] AIRY, 'On Tides and Waves', *Encyclopaedia Metropolitana,* vol. V, § 416. See also *Journal des Mathématiques,* Ser. 3, vol. I, Paris, 1875, pp. 399—450. Quoted by KRÜMMEL *op. cit.* p. 90; and A. GEIKIE, Text-Book of Geology, 1893, p. 438.

[4] TIZARD, *Proc. Royal Soc.*, vol. XXXV, 1883, p. 208, quoted by KRÜMMEL *op. cit.* p. 90.

Direct observations of oscillatory movements in the sea. Aimé has proved by experiments that the waves with a height of 1·5 m. may cause considerable horizontal oscillations (70—80 cm.) at a depth of 14 m., and in the road of Algier, 1 kilometre from the shore, he could prove the occurrence of appreciable oscillatory motion at a depth of 40 m.[1]. Cialdi states that in 1831, during the diving-work on H. M. S. Thetis of the English Navy, which had been wrecked at Cape Frio on the Brasilian coast, the diving bell was always during strong wind and not seldom in comparatively calm weather, exposed at depths of 18—20 m., to violent horizontal oscillations of 1·5 m. amplitude, which made the work very dangerous to the divers who were thereby liable to knocks against the rocks[2]. Hermann Fol states from his own experience that in the Mediterranean the task of the diver becomes very difficult, when there is a "swell" on, "an irresistible force makes him oscillate like a pendulum". "This see-saw motion of the water is felt nearly as much at 30 m. as at 10 m. of depth". He also mentions that "the fishermen who use trawl or drag nets upon extensive banks, situated quite out at sea, know that after a storm, these banks at depths of 50 m. and more, are completely swept clear of their usual inhabitants"[3].

Observations on the sea-bottom. Mr. Siau has by soundings investigated the occurrence of ripple-marks on the sea bottom off the coast of Reunion Island in the Indian Ocean, and he states that the deepest sounding at which the impression on the tallow of the lead distinctly demonstrated their existence, was one of 188 m.[4]; ripple-marks, however, are not merely formed by waves but also by currents. Mr. Cialdi asserts that the movements of waves may disturb fine sand on the bottom at a depth of 40 m. in the English Channel, 50 m. in the Mediterranean, and 200 in the open ocean[5]. According to Mr. A. R. Hunt's observations of rolled shells, the bed of the sea on the coast of the English Channel may be disturbed by wave action to depths of about 70 m. (38 and 41 fathoms)[6], and he believes that the clean sand and shells at 180 m. (100 fathoms) and more, at the mouth of the English Channel prove that the wave action may even reach down to this depth[7]. He draws attention to the fact that the codfish of the Newfoundland-Bank from depths of 55—91 m., very often have shells of *Mya truncata*, which lives at a depth of 8—10 inches (20—25 cm.) below the surface of the sand on the bottom, in their stomachs[8]. The fish cannot possibly get at these moluscs, if the overlying sand be not disturbed or washed away by the oscillatory movement of the waves. But as the wave motion is so violent at such depths, we must expect it to have appreciable effects even at much greater depths[9].

In response to a question from me on the subject, Sir John Murray says in a letter, dated 23 May, 1903, that erosion in the sea "does take place at 250 fathoms (456 m.) on the Wyville Thomson Ridge; but this is a tidal affair. At 100 fathoms (180 m.) fine mud

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[1] Aimé, *Ann. de Chimie et de Physique*, Ser. 3, vol. V, 1842, pp. 417 *et seq.*, quoted by Krümmel *op. cit.*, pp. 30—32.

[2] Cialdi, *op. cit.* § 776, quoted by O. Krümmel, 'Handbuch der Oceanographie', vol. II, 1887, p. 91.

[3] Hermann Fol, *Revue Scientific*, June 7th, 1890; quoted by M. Stirrup, *Geol. Mag.*, Dec. III, vol. VII, 1890, p. 430.

[4] Siau, 'De l'action des vagues à de grands profondeurs', *Annales de Chimie et de Physique*, Ser. 3, vol. II, 1841, p. 120; *Comptes Rendus*, vol. XII, p. 774.

[5] Cialdi, 'Sul moto ondoso del mare', 2nd edition, Rome, 1866, Chapt. 3. Quoted by A. Geikie (Text-Book of Geology, 1882, p. 423) from Delesse, 'Lithologie des Mers de France', 1872, p. 111.

[6] A. R. Hunt, 'On the Formation of Ripplemark', *Proc. Royal Soc.*, vol. XXXIV, 1883, pp. 1—18; See also *Geol. Mag.*, Dec. III, vol. VII, 1890, p. 521.

[7] A. R. Hunt, 'Wind Waves and Tidal Currents', *Geol. Mag.*, Dec. III, vol. VII, 1890, p. 527.

[8] J. Gwyn Jeffreys, 'British Conchology', vol. III, p. 69.

[9] *Proc. Royal Soc.*, vol. XXXIV, 1883, p. 15.

is moved off the north of Scotland in great storms; but the depth at which sand grains are moved is much less".

Admiral Sir WILLIAM J. WHARTON has shown me the great favour to make inquiries amongst practical people, as to the depths at which the sea-bottom has actually been observed to have been disturbed by wave motion; and just as this is going to press, he sends me the following interesting communication from Capt. FIELD, one of the best British surveying officers:

H. M. S. "Research", Loch Eriboll, 4th August, 1903.

"A steam trawler having come in here, I have taken the opportunity to make enquiries on the subject of the depth at which the bottom is disturbed in heavy gales, which you asked me about some time ago. I found the skipper of the trawler a very intelligent man and he told me that in 20 to 30 fathoms on a smooth day they bring up no sea weed in their net, but the next day if a heavy sea got up they would be full of it.

He spoke of this as being a matter of the most common and ordinary experience possible, and was convinced that it was due to the disturbance of the weed on the bottom by the heavy sea when it was running, and when not so disturbed they did not catch the weed.

In greater depths of 40 fathoms, the quantity of weed they catch is much less. Occasionally he has had weed at as much as 50 fathoms but in small quantities, and only when there has been a very heavy sea; he has never got any in 60 fathoms, and thinks it possible it may not grow at that depth. He is quite positive that they only catch the weed immediately after or during heavy weather, and if that is so, it points to it having been stirred up on the bottom by the action of the swell,

I put no leading questions to him, but merely asked him if he could give me any idea as to what depth the bottom was disturbed in heavy gales judging from the nature of the stuff he brings up. He then started immediately to tell me what happened on a fine day and on a rough day, and the conclusions he drew. If I come across another trawler I will see if this is corroborated."

A. PENCK[1] mentions that the volcanic islands are worn down by marine denudation: The island *Ferdinandea*, between Pantellaria and Sicily, was formed in June, 1831, and was in December of the same year abraded to 70 m. below sea-level[2]. The volcanic cone formed in June, 1867, in the Somoa Islands, had already the next year been abraded to a depth of 116 m.[3].

Sir WILLIAM J. WHARTON[4] has drawn attention to the fact that "Sabrina Island, on the flank of St. Miguel in the Azores, was formed in 1811, all of loose material, and was washed away to a depth of 15 fathoms in a short time. What water is now over it is not known". He also mentions the fact "that submarine cables have been taken up which show evidence of heaving been moved and chafed at even greater depths" than 80 fathoms. "Cables have been recovered which show that breakage has occurred from their being moved in 260 fathoms", and he has in his "own posession a steel wire forming part of the outer covering of the Brazilian cable, picked up from 140 fathoms, which is worn down on one side as with a file". It seems to me, however, to be doubtful whether these cables have been moved by wave action, as there may often be disturbances of very different kinds on the sea-bottom[5].

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[1] A. PENCK, 'Morphologie der Erdoberfläche', 1894, vol. II, p. 653.
[2] C. W. C. FUCHS, 'Die vulkanischen Erscheinungen der Erde', 1865, p. 355.
[3] G. A. TURNER, *Scott. Geogr, Mag.*, vol. V, 1889, p. 235.
[4] W. J. L. WHARTON, 'Foundation of Coral Atolls', *Nature,* vol. LV, 1897, p. 392.
[5] KRÜMMEL mentions in a similar connection (*op. cit.* vol. II, p. 30) that cables have been damaged on rocky bottom at depths of 1200—1800 m., but it seems impossible that this can have been directly due to wave action of any kind.

Currents. With regard to the velocity of the tidal and of the oceanic currents along the bottom of the open sea we know very little or nothing by direct observation, and before systematic investigations have been made with specially constructed current-meters it is hard to say whether the currents over the continental shelves are rapid enough to erode the floor or to disturb the deposits.

The experiments made by the several investigators, to ascertain the velocity of a current necessary to disturb or move the bottom deposits, give somewhat contradictory results [1]. The following table will give an idea of the transporting power of currents — chiefly river currents — at different velocities according to different authors:

Velocity in metres per Second.		
0·0029	m.	will lift the smallest pieces of Globigerina-shells. THOULET [2].
0·029	„	will lift greater pieces of Globigerina. THOULET.
0·077	„	will just begin to work on fine clay. STEVENSON [3], FORBES [4].
0·15	„	will lift fine sand. STEVENSON, LYELL [5].
0·20	„	will lift sand as coarse as linseed. STEVENSON.
0·213	„	will disturb fine fresh-water-sand. FORBES.
0·305	„	will sweep along fine gravel. STEVENSON.
0·337	„	will disturb sea-sand. FORBES.
0·40	„	will just begin to work on rounded pebbles 6 mm. in diameter. BLACKWELL [6].
0·61	„	will move shingle of the size of peas. FORBES.
0·61	„	will roll along rounded pebbles 25 mm. (1 in.) in diameter. STEVENSON.
0·70	„	will just begin to work on pebbles 12·7 mm. in diameter. BLACKWELL.
0·897	„	will transport pebbles of the size of beans, when they have first been stirred up. SUCHIER [7].
0·92	„	will sweep along slippery angular stones of the size of an egg. STEVENSON.
0·923	„	will roll along pebbles of the size of a nut, when they have first been stirred up. SUCHIER.
1·247	„	will carry along pebbles of the size of peas and nuts, even from rest. SUCHIER

Prof. OTTO PETTERSSON has lately made some very important measurements of the currents in Skagerak and the Baltic [8]. PETTERSSON has kindly sent me the following interesting table of those of his current measurements which were made near the sea bottom.

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[1] See A. PENCK, 'Morphologie der Erdoberfläche', vol. I, 1894, pp. 281—284.

[2] THOULET, 'Expériences sur la Sedimentation', *Annales des Mines*, 1891.

[3] DAVID STEVENSON, 'Canal and River Engineering', p. 315, quoted by GEIKIE, Text-Book of Geology, 1882, p. 368.

[4] FORBES, 'Abrading Power of Water at different Velocities', Proc. R. Soc. Edinb., vol. III, 1856—57, p. 474.

[5] LYELL, 'Principles of Geology', 10th ed., vol. 1, p. 348.

[6] Quoted by BEARDMORE, 'Manual of Hydrology', 1872, p. 7.

[7] SUCHIER, 'Die Bewegung der Geschiebe des Oberrhein', *Deutsche Bauzeitung*, 1883, No. 56, p. 331.

[8] P. T. CLEVE and O. PETTERSSON, 'Hydrographic-biological Researches by the Swedish Comission in the Skagerack and Baltic', pp. 3, 4, 7, 12, 13, *Svenska Hydrografisk Biologiska Kommissionens Skrifter*, vol. I.

Station.	Locality.	Date.	Depth of Sea in metres.	Depth of Observation in metres.	Velocity of currents in centimetres per second.
So.	57° 40′ N. Lat. 11° 25′ E. Long.	Aug. 2, 1901	70 m.	60 m.	16·5 cm./sec.
		Oct. 9, „	80 „	60 „	61 „
		Febr. 2, 1902	90 „	80 „	36 „
		Aug. 15, „	88·5 „	80 „	35 „
SII.	57° 55′ N. Lat. 10° 37′ E. Long.	Aug. 7, 1901	140 m.	60 m.	32·2 cm./sec.
		Febr. 2, 1902	137 „	130 „	18 „
		Nov. 19, „	133 „	120 „	27 „
SIII.	58° 12′ N. Lat. 10° 29′ E. Long.	Febr. 2, 1902	298 m.	280 m.	17 cm./sec.
		Nov. 20, „	252 „	240 „	18 „
		March 1, 1903	142 „	135 „	19·8 „
SIV.	58° 13′ N. Lat. 11° 1′ E. Long.	Febr. 3, 1902	110 m.	100 m.	32 cm./sec.
SVI.		Febr. 4, 1902	120 m.	110 m.	5·8 cm./sec.
SVII.	58° 45′ N. Lat. 9° 50′ E. Long.	Febr. 5, 1902	516 m.	450 m.	18 cm./sec.
SX.	58° 36′ N. Lat. 10° 34′ E. Long.	Febr. 8, 1902	175 m.	165 m.	50 cm./sec.
Smygehuk.		Oct. 10, 1901	40 m.	35 m.	37 cm./sec.
NW. Bornholm.		Oct. 11, 1901	75 m.	70 m.	45 cm./sec.

The observations were made by Pettersson's current-meter[1] which was lowered from a gun-boat lying at anchor. He informs me that by bearings of land and observations of the compass on board, it was ascertained that the movements of the heavy gun-boat were quite insignificant during the observations; as, however, according to my experiences slight movements, *e. g.* less than 15 cm. per second, may be difficult to observe in this way, we shall have to consider the velocities found, as maximal values only.

It is an interesting fact that at the same station (cf. Station So and SII) the bottom current may at depths of less than 130 m. vary much, on different dates, while at greater depths there are probably smaller variations (cf. Station SIII). We see that the velocity of the current near the bottom at depths greater than 200 m. were at any rate less than 17 or 18 cm. per second, and on the bottom itself it has probably only been a fraction of this. According to the table on p. 139 a current of 7·7 cm. per second will just begin to work on fine clay, and a current of 15 cm. will lift fine sand. Considering that the velocities found probably have to be reduced by the errors due to the movements of the ship, it is therefore hardly probable that these bottom currents observed by Prof. PET-

[1] L. c. p. 17.

TERSSON have had much disturbing influence upon the sand and clay deposits of the sea-bottom. But at Station Sx he observed a velocity of as much as 50 cm. per second at a depth of 165 m., ten metres above the bottom. Even if we assume that the actual bottom current has been a good deal less rapid, it must have had an appreciable transporting capacity, and was possibly able to transport coarse sand and thus have had an eroding effect on the sea-bed [1].

But PETTERSSON's observations were made in an enclosed shallow sea through which, however, the currents to and from the Baltic Basin pass, and where special conditions may consequently prevail. We have at present no observations which may give us any trustworthy information as to the velocities of the bottom currents of the ocean on the continental shelves. According to Prof. MOHN's calculations the bottom-current along the continental slope off Nordland (between 62° and 70° N. Lat.) should have a velocity of

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[1] After the above was written I made some observations of the bottom currents of the sea by specially constructed instruments so arranged as to exclude the disturbing influence of the movements of the ship. It was found that even in an enclosed fjord, only 70 m. deep, errors of 8 or 10 cm. per second may easily arise through the movements of the ship at anchor, and in the deep open sea the errors are probably much greater, if the currents to be measured are very slow and special precautions be not taken. Where the bottom currents are rapid the errors will be of less significance. Although the results of the observations are not yet ready for publications, I may mention here that I was able to prove movements of the water near the bottom of the sea (60 cm. above it) even in enclosed fjords; but these movements were not uniform and regular, the velocities varied much and they were evidently more or less oscillatory or perhaps rather vortical. In the encloced fjords (Topdals Fjord near Christiansand, and Søndeløv Fjord near Risør) the movements of the water 60 cm. above the bottom (at depths of about 60 or 70 m.) might in the course of 2 or 3 minutes vary between a few millimetres and 1 or even 2 cm. per second, and the direction is also very variable. At a station about 5 miles NE of Skagen (depth 75 m.) near Pettersson's Station So the velocity of the bottom-current (60 cm. above the bottom) varied during intervals of less than 3 minutes between about 9 and 15 cm. per second, the direction was also variable, between WSW and S. Higher above the bottom the direction of the current was much less variable, it did not at any rate vary more than a point during the 6 or 10 minutes such an observation generally lasted. Whether the velocity of the current varied much at these depths was not observed, as only the mean velocity was measured. The following observations were made, the values of the velocity are only approximate:

Height above Sea-Bottom in metres.	Depth below Sea-Surface in metres.	Mean Velocity of Current, in centimetres per second.	Mean Direction of Current, during observations.
0·6 m.	74.4 m.	9.6 cm./sec.	SWbS
1·2 „	73·8 „	21·5 „	SWbW
5 „	70·0 „	27 „	W
15 „	60·0 „	36 „	WSW
35 „	40	51 „	W
65	10	68 „	W
73	2	80 „	W

about 15 cm. per second at a depth of 549 m. (300 fathoms)[1], but these calculations are of course very uncertain, and were based on very uncertain data. It has to be taken into due consideration that the surface relief of the sea-bed, even at great depths, has a very appreciable influence upon the oceanic currents[2], and that even gently rising slopes may greatly reduce the velocity of the currents. It is therefore improbable that the bottom-currents on the continental shelves inside their edges, can be as a rule vary rapid.

The tidal currents may perhaps be appreciable at some places even at the bottom of the open sea, but we have at present no observations enabling us to form any approximate idea as to their possible velocities along the bottom.

Thus from known observations we cannot arrive directly at any trustworthy results whether the currents over the floor of the continental shelves are as a rule sufficiently rapid to transport or disturb the bottom deposits. But it is nevertheless probable that in connection with the oscillatory wave movement of the water they are of much importance in this connection. HUNT has pointed out that the oscillatory currents produced by wave movements have a greater effect in producing ripple-marks than have stationary currents: while G. H. DARWIN found by his experiments that a velocity of more than 15 cm. was necessary to form ripple-marks on the bottom of his trough[3], HUNT found that by oscillatory currents, velocities of less than 10 cm. sufficed to form ripple-marks less than 2·5 cm. long. We have seen in the table above, that a much greater velocity is required to put sediments or pebbles in motion, than to move them after they have been stirred up.

It is therefore probable that down to certain depths the velocities of the currents are sufficient to cause the transportation of the sediments as long as they are suspended in the water, or after they have been stirred up by wave action. The result must be that the sediments will not be left at rest but will be on the move until they reach a depth where the transporting capacity of the moving water is not able to disturb them. This depth will

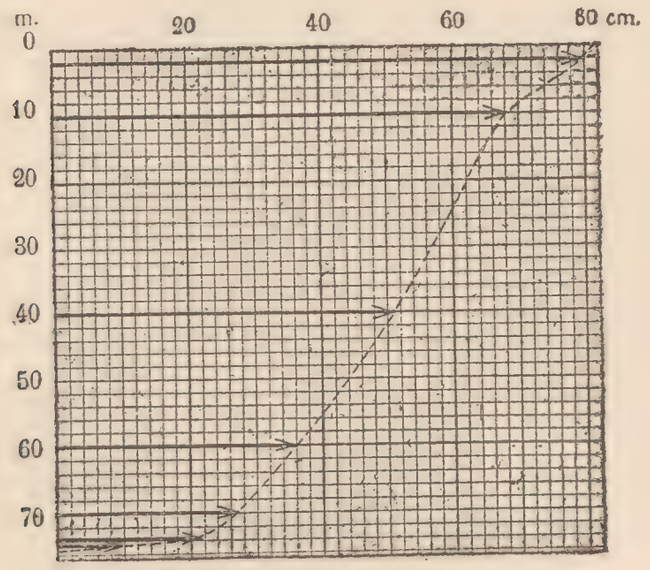

Fig. 3.

The direction of the current means here the direction from which the current came, it was consequently running eastward, except near the bottom where it was more irregular and turned more northward, probably following the depressions of the bottom. It is seen that the velocity of the current decreases rapidly downwards near the bottom (see Fig. 3), which was covered by *sandy clay*.

[1] H. MOHN, 'The North Ocean', *The Norwegian North Atlantic Expedition* 1876–1878, Christiania 1887, Pl. XLIV, and p. 183.

[2] NANSEN, 'Some Oceanographical Results of the Expedition with the Michael Sars in the Summer of 1900'. *Nyt Mag. f. Naturvidenskab.*, vol. XXXIX, Christiania, 1901, p. 152.

[3] G. H. DARWIN, 'On the Formation of Ripplemark in Sand', *Proc. Royal Soc. London*, vol. XXXVI.

differ at different places according to the strength of currents and wave action. On the continental shelves along the coasts of the open ocean it will probably to a great extent vary between 150 and 200 m. for the greater part of the terrigenous sediments; on the continental slope more exposed to the oceanic currents, this depth will be greater, while in more or less enclosed shallow seas, *e. g.* the North Sea, it will be less; for Globigerina Ooze and other deep sea deposits it will generally be much greater.

By studying the nature of the sediments on the sea-bottom we have an indirect method of determining the transporting capacity of the bottom currents; for if the sea-bottom has been submerged during a sufficiently long period we must expect it to be covered with sediments, the coarseness of which will vary according to the transporting capacity of the bottom currents and the wave-action. Studied in this manner the distribution of the sediment of the continental shelves supports the above view of the depth of the eroding or transporting effects of currents and wave-action.

On the Norwegian continental shelf north of 62° N. Lat., for instance, clay or sandy clay is generally not found higher than the 200 metres contour. All higher parts are composed of sand, or sand and shingle, and on the highest parts there are almost always coarse materials, coarse sand, shingle, and stones, or rocks (see Sections 8—34). It is evident that all clay has been washed away from the high parts of the shelf or has never been allowed to settle there; fine sand has also been washed away, but is deposited on the somwhat deeper parts, the sand and clay, is deposited still deeper, and the pure clay and mud in the deepest hollows of the shelf, or on the continental slope. The depths at which we find the clay and the sandy clay on the shelf, may differ much, evidently depending upon the situation, according as there are rapid movements of the water or not.

There is an obvious tendency towards the following general rules: parts of the continental shelf rising above the 140 or 130 metres contour are covered by coarse materials, coarse sand, shingle or stones, if they are not composed of rock; at depths between 140 m. and 200 or 250 m. fine sand is very common, while at greater depths clay or sandy clay prevails on the flat floor of the continental shelf.

On the *North Sea* platform we find similar conditions. The bottom of the *Norwegian Channel* is covered by mud and clay below the 200 m. contour (Sections 36—38, Pls. XIX—XX), near its mouth (Section 35) the mud and clay line lies deeper, near 300 m., while in the more sheltered sea south of Section 38 it rises and approaches the 100 m. contour on the side slopes of the channel (Sections 39—40). On the flat platform, clay or sandy clay may be found at very shallow depths (Section 39).

Where the *continental slope*, outside the edge of the shelf, is comparatively steep, — *e. g.* on Lofoten-Vesteraals Eggen (Section 11—20, Pls. XII—XIV) and to some extent also on Storeggen (Sections 29—34, Pls. XVI—XVII) — the upper limit of the continuous bottom layers of sandy clay (S. L.) clay (L.), and mud (Sl.), is generally found at about 600 or 800 m.,

whilst it is found much higher on the continental shelf inside its edge and especially in its hollows, and also on the continental slope, where its inclination is comparatively small, *e. g.* off Helgeland (Sections 22—26). If Section 25 (Pl. XV) be compared with Sections 11—17 (Pls. XII—XIII) the difference in this respect is striking: whilst in the latter sections hardly any clay or sandy clay is found higher than 600 or 700 m. below sea-level; both clay and sandy clay is found almost everywhere in Section 25 below a depth of 200 m. It is chiefly the Halten Bank which rises above the limit where clay can be deposited, and which is therefore covered with sand and shingle. A sounding of 290 m. where sand and shingle was found is an exception, but this place may be considered as being at the edge of the continental shelf where the currents (and perhaps also wave action?) may have greater effect upon the bottom. By a careful study of the sections we shall find also, as a general rule, that the clayey deposits tend to cover the flat parts of the shelf, its hollows, and its landward slopes, while the seaward descents are generally covered by sand, shingle, or even stones, see for instance Sections 20, 22, and 29. The edge of the continental shelf is hardly ever covered by clayey deposits, there is always sand, or shingle and stones, or even rock; this is even the case where the shelf elsewhere, is almost entirely covered by clayey deposits, Section 22 (Pl. XIV) is a good example.

The above facts seem to prove that the *continental slope* — where it is sufficiently steep and exposed to the open ocean — is swept by currents sufficiently rapid to wash clayey deposits and mud down into depths of 600 or 700 m. Where the slope is gentler, the bottom currents are less rapid, and are not able to wash the clay down to such depths; this depth of the clay-line consequently increases with the slope. On *the edge of the continental shelf* there is always comparatively rapid water movements preventing clay and mud from being deposited. The *floor of the continental shelf*, inside the edge, especially the flat parts of it, its landward slopes, and its hollows, where clayey deposits may be allowed to settle below 200 or 250 m., is more sheltered against the movements of the water, while the seaward slopes of the protuberant parts of the shelf are more washed by the water movements.

From what has been said it may be concluded, that if the floor of the continental shelf lies below the upper limit of the deposition of the fine sand and clay, we may call it the *fine-sand line* and *clay line*, it will be covered by such deposits and will gradually be built up until it reaches this level, after which it will grow no higher, but will grow in width, as the sediments will be gradually swept seawards and will finally be deposited either in hollows of the shelf or on the continental slope where the water is sufficiently deep. As, however, the *clay line* lies very deep on the continental slope, according to the steepness of its descent, it seems probable that a continental shelf built up in this manner, can never get a very steep continental slope.

If the floor of a continental shelf be liftet above the clay and the fine-sand lines it will be eroded by the movements of the water, because clay and sand will gradually be washed away seawards or into hollows. We must consequently expect that the continental shelves off Lofoten-Vesteraalen and Søndmør-Romsdalen are gradually being eroded in this manner, while the continental shelf off Helgeland (Sections 20—28) is being built up. If a continental shelf of the latter type be originally much dissected, the movements of the bottom water will be accelerated over the protuberant parts, and the sediments will on the whole be deposited in the more sheltered submarine fjords and hollows, until the floor has been pretty well levelled, when the sediments will be more uniformly distributed.

There is thus actually a tendency in the sea to keep the surface of the continental shelves at a certain normal depth below existing sea-level, and this depth will vary somewhat according to the local conditions. If the vertical movements of the shore-line be slower than the rate at wich a continental shelf composed of loose material, is built up or eroded by the water movements, its surface will always remain at practically the same depth below sea-level.

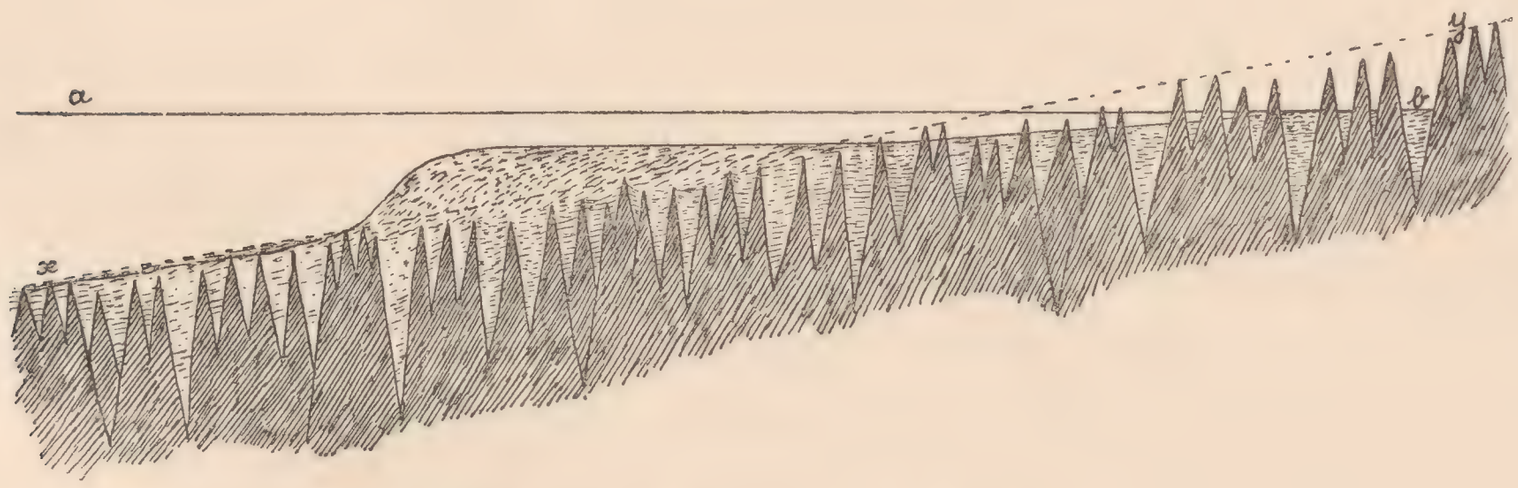

Fig. 4. *ab*, Sea-level. *xy*, Land-slope.

The characteristic features of a continental shelf built up exclusively by sea deposits and developed to maturity, would be: a very smooth floor but on the whole perhaps somewhat steeper than those of the previous types, this floor will be composed of sands near the coasts and of clayey deposits farther from land. The edge will not be very sharply defined, it will be more or less rounded, and the continental slope will not be very steep near the edge, but will increase somewhat seawards, and will again decrease at greater depths and approach the original continental slope (fig. 4). The shelf will form no hori-

zontal incision in the original slope of the continent towards the floor of the ocean (fig. 4, *xy*), but will be built up as a terrace on this slope.

A continental shelf standing above the normal depth will gradually be covered by sediments composed of coarser grains, the finer grains being washed away; the edge may become more sharply defined, and the continental slope beyond the edge may be steeper than in the former case, on the other hand there may be a tendency to round it off or to form a new and lower shelf on the slope below the clay-line.

The width of a continental shelf built up by marine sediments during a certain period will depend on the *situation of the coast*, on the *amount of waste* carried into the sea along the coast, and further on the original *inclination of the sea-bottom* from the shore towards the oceanic floor. The *situation of the coast* is important in so far as it makes much difference whether the coast is sheltered or is exposed to the full play of wave action and oceanic currents, which may wash the waste away from the coast, the waste is for instance sooner deposited in an enclosed sea, than on an open coast. It may also be of some importance whether the prevailing currents of the ocean outside run in towards, parallel to, or away from the coasts. The situation of the coast may also influence the *depth* of the continental shelf as mentioned above (p. 135); it actually seems a common occurence for the edges of the continental shelves to lie at greater depths along the open coasts of great oceans than in more enclosed seas or in ice-covered seas where the wave action is less. The continental shelves of the exposed western coasts of Europe lie on the whole deeper than the shelf north of the Siberian coast (the edge at 100 m.), in the Kara Sea (edge in about 40—50 m.), on the west coast of Greenland, and on the west coast of Africa. It may be due to differences partly in the coastal sedimentation and partly in the marine denudation, as will be mentioned in a subsequent section (cf. also p. 119).

The *amount of waste* carried into the sea increases with the distance of the continental watershed from the coast, with the height and slope of the continental surface, as well as with the precipitation, and the atmospheric erosion on the continent. The continental shelves of the world may perhaps actually have a tendency to be wide outside coasts with extensive drainage areas, I may instance the Siberian coast, the North Sea, the French side of the Bay of Biscay (differing much from the Spanish side), the east coast of North

America and South America (off the mouth of the Amazon and La Plata rivers), the East China Sea, the northern termination of the Bay of Bengal, and the Arabian Bay, the northern coast of the Black Sea, etc. The difference between the north coast of Alaska, where the shelf is narrow, and its west coast, bounding the Bering Sea, as well as the North Siberian Coast, with the broad continental shelves, may also be mentioned. The situation of the watershed close along the Pacific coast might thus seem to explain the striking differences in the continental shelves of the Atlantic and Pacific coasts of North and South America. But the chief explanation is probably that the Pacific coasts are relatively young. It is also probable that many of the above examples of broad continental shelves have to be otherwise explained, and, for instance, the exceptionally broad continental shelf off the east coast of southern Patagonia can hardly be explained in this manner. It ought also to be remembered that peneplains will most easily be formed on those sides of the continents where the watershed is farthest from the coast.

If *the slope of the sea-bottom off the coast* be steep, much more waste is required to build up a continental shelf of a certain width than on a gentle slope, and it will require much longer time, considering that the steeper continental slopes are more washed by the oceanic currents, the continental shelves may even be formed only with great difficulty there, especially if the coasts have a very limited drainage area, — *e. g.* northern Spain, Peru — such steep continental slopes and coasts are moreover often comparatively young.

(4.) *The Formation of Continental Shelves by Glacial Drift.*

During glacial periods great quantities of glacial drift have been deposited on the sea bottom along the coasts of the ice-covered lands, outside the margin of the ice-sheets, and this drift may have contributed more or less to the formation of continental shelves. It is evident that the surface of the glacial drift heaps deposited in the sea will be much regulated by the level of the sea, and the base-level of wave action and current erosion, although not to the same extent as in the case of ordinary sea deposits. If glacial drift has been deposited above this base-level, the movements of the water will continually try to plane it down to this level, but as the glacial drift is comparatively coarse, the surface of a continental shelf of this type may remain stationary

at higher levels than would a shelf built up of fine sea deposits. As the coarseness of the glacial drift may vary at different places the surface of the shelf may also remain comparatively uneven if not levelled by later deposits.

The characteristic features of a continental shelf formed exclusively in this manner, would therefore be: a comparatively uneven and more or less irregular surface, to a great extent covered by coarse material, coarse sand, shingle, pebbles, and stones or boulders. The continental slope may be steep — much steeper than in the former case — but it may also be gentle. The continental shelf formes no horizontal incision in the land slope and the continental slope, but rises as a terrace on this slope, as in the former case.

Glacial drift is found on the continental shelves of most lands, which have been formerly glaciated, *e. g.* Norway, the British Isles (and the North Sea), Iceland, Greenland, Newfoundland, eastern Canada, and Patagonia. On the continental shelf off north-eastern Siberia gravel was found at several places during the Jeanette Expedition (*ante* p. 19).

THE ORIGIN OF THE NORWEGIAN CONTINENTAL SHELF.

Let us now as an example examine which process might have been of most importance during the formation of the Norwegian Continental Shelf, which we know best. The topography of this shelf as well as the composition of its surface, indicate that it is far from having been developed to maturity: its present surface sculpturing, must be of comparatively young age; it is no homogeneous structure, exemplifying the ideal features of any of the above methods of formation: it is not merely an ancient coast platform which has been submerged and filled up more or less, and not a submerged peneplain, neither is it merely built up by sea deposits, or by glacial drift, — it seems as if all these processes have played their part.

The relation between the geological structure of the coast and the continental shelf. If a map giving roughly the great geological features of the Norwegian coast, between 62° N. Lat. and Finmarken (Pl. XI a), and a map of the continental shelf (Pl. XI) be compared it must strike one to what a great extent the height of the continental shelf seems to depend on the geological structure of the coast, and perhaps to an even still greater extent than

we found was the case with the *coast platform.* Along the Norwegian coast we find rocks belonging chiefly to three systems: 1) ancient, relatively hard rocks generally referred to the *Archæan system,* 2) weaker sedimentary rocks and post-Silurian igneous rocks building up the socalled *Norwegian mountain system,* 3) the *Finmarken system* (Gaisa- and Raipas-systems) possibly belonging to the Timan mountain system. It is a remarkable fact that at those places where the two latter systems descend to the coast the continental shelf outside is very low, — generally more than 250 or 300 m. below sea-level, — and is very broad, but where the coast is built up of rocks belonging to the first system the continental shelf is very high, rises to within 100 m. or less of the sea-surface, and is generally narrow: The rocks of the Norwegian mountain system descend to the coast between the Bindal Fjord (in 65° 13′ N. Lat.) and the Sag Fjord (in 68° N. Lat.) and just off the Bindal Fjord and northward there is a sudden change in the level of the continental shelf (see Pl. XI). The rocks of this mountain system also descend to the coast in a NN-Easterly direction between Tromsø and Hammerfest, and in this region there is also a sudden change in the heights of the continental shelf as well as in the level of the coast platform (see above p. 117). East of Hammerfest is the Finmarken system with a very extensive but low continental shelf outside, and also a low coast platform as mentioned before (p. 119).

In the *Søndmør* and *Romsdalen region,* between the Nord Fjord (in 62° N. Lat.) and Kristiansund or the Smølen Island (63° 15′ N. Lat.), there are almost exclusively *Archæan* rocks, gneiss and granite, which have a very wide extension inland; off this coast the continental shelf is narrow and very high, rising to within 100 and even 80 m. of the sea-surface (see above p. 43), its sharply defined edge is at depths of 130—150 m. (Sections 30—33, Pls. XVI—XVII; and Longitudinal Section Pl. XVIII). To the north-east of the above Archæan region, a relatively narrow prolongation of its rocks extends along the coast as far as the Bindal Fjord and ends in a narrow strip with a last outpost in Torghatten (cf. VOGT, *l. c.* p. 5). Off this coast the continental shelf greatly changes its character, it becoms gradually broader and on the whole lower, but there are still high banks rising above the 200 m. contour to within 154, 102, and 120 m. of the sea-surface: — the bank in 63° 50′ N. Lat. (Section 27), the Halten Bank (Section 25), and the bank

off Bindalen in 65° 15′ N. Lat. (Section 24). It seems probable that these elevations belong to the Archæan region, while the surface of the other parts of the continental shelf, inside and outside these, has been composed of weaker rocks belonging to the 'Norwegian mountain system', for such rocks occur in a line along Trondhjems-Leden on the inner sides of the Smølen and Hitteren as far as the Skjørn Fjord, Beitstad Fjord, and Lake Snaasen (Pl. XI a), and it is evidently to this circumstance that this remarkable line of the longitudinal fjords and valleys (mentioned above p. 45), which is 270 kilometres long (from Hustadviken to Snaasen), is due. The great longitudinal submarine fjords inside the Halten Bank and inside the Fro Islands (see above p. 54) are evidently carved in similar weak rocks.

The *Lofoten-Vesteraalen Archæan* and *Gabbro region* extends in a NN-Easterly direction from Lofoten and Vesteraalen along the outer coast of the Senjen Island to Ringvasø and Vannø, etc., north of Tromsø (see Pl. XI a), and it seems probable that it extends farther in the same direction below sea-level, forming the great bank there above the 200 m. contour (see Pl. XI and XI a). The continental shelf off this Archæan-Gabbro region is narrow and exceptionally high, with a sharply defined edge and an unusually steep continental slope outside (see above pp. 38—39); especially is this the case off Vesteraalen, Andø and Senjen, where the general floor of the shelf rises to within 80 m. or even 70 m. and less of the sea level (see Sections 12—15, Pls. XII—XIII; and also Longitudinal Section Pl. XVIII); the shelf narrows to a width of 18 kilometres and less, off Andø. It is a noteworthy fact that north of Senjen where the rocks of the Norwegian mountain system approach the outer coast, the shelf becomes gradually broader and deeper in an exactly similar manner as north of Romsdalen: at first its inner part remains high while its outer part slopes to greater depths (cf. the Malangen Bank Section 11, and Long. Sect. Pl. XVIII), while farther north the whole shelf becomes deeper and broader, but the inner part still remains much the highest (Pl. XII, Section 10).

It seems highly improbable that the apparent relation between the configuration of the continental shelf and the geological structure of the Norwegian coast is a mere accident; it indicates that *the topography and width of the Norwegian continental shelf have to a very great extent been determined by the tectonic structure of the underlying rocky ground, the*

weak rocks having been eroded deeper than the harder rocks. The continental shelf must thus to a great extent have been formed by erosion of some kind, of the underlying rocks and cannot merely have been built up by river waste or glacial drift. If the latter had been the case we should be obliged to assume that there had been great vertical dislocations along the coasts as recently as after the formation of the continental shelf; but no evidences of such recent and great mountain movements have been observed[1], and besides:

The occurence of submarine longitudinal valleys or fjords on the continental shelf between Søndmør and Lofoten (described on pp. 44—46, and 54—58, see also p. 118) is, according to my view, conclusive evidence that the underlying ground of at least the innermost part of the shelf is solid rock at no great depth below the surface; for, as I have pointed out, this longitudinal arrangement of the valleys and fjords, both on the land and on the sea-bottom, stands in genetic relation to the tectonic structure of the underlying rocks. These prominent features of the surface relief of the shelf cannot therefore be due to an incidental accumulation of sediments or glacial drift, but must originally have been sculptured by erosion, and, as mentioned on pp. 57—58, the longitudinal valleys must owe their prime origin to the subaerial erosion of running water.

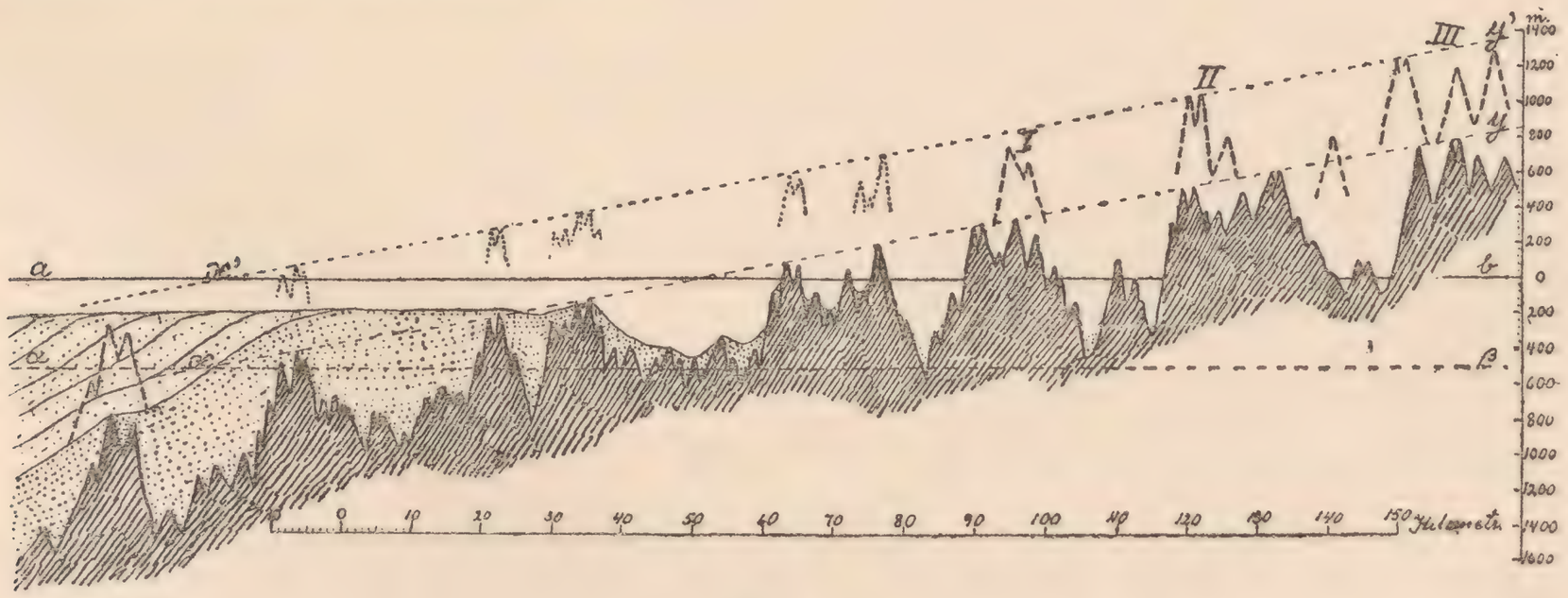

Fig. 5.

As the traces of the longitudinal fjords are most distinct near the coast and disappear to a great extent in the outer parts of the shelf, it might seem possible that the latter has not been cut by erosion, and especially not marine denudation, but has been chiefly built up by sediments and glacial drift, along an originally much dissected and afterwards submerged coast, as illustrated in fig. 4. Let us assume that the Norwegian coast had acquired a fairly regular land-slope before it was submerged, and let fig. 5 be a section of

[1] The local post-Silurian dislocations on Andø, pointed out by SUESS (Antlitz der Erde, vol. II, pp. 72, 93) and VOGT (*l. c.* p. 7) cannot be appropriated in favour of such a theory.

the coast of Norway near the Halten Bank, between 64° and 65° N. Lat., the vertical scale of the section being exaggerated 25 times. If the coast be submerged belov a sea-level *a b*, and if the submerged land be filled up by glacial drift outside the margin of an ice-sheet which extended beyond the innermost submerged longitudinal valleys, a continental shelf with traces of these valleys might well be formed, but the peaks of the new coast would then rise quite gradually inland, indicating a fairly regular slope *x y*. But the highest peaks of the present coast rises nearly 450 or 500 m. higher, as indicated by the peaks I, II, and III, drawn with broken lines; and in order to represent the real conditions the slope of the mountains would have to be lifted to *x' y'*, or the sea-level *a b* might be lowered to *αβ*. The innermost mountain peaks of the continental shelf must consequently have been cut down several hundred metres, while at a distance of more than 100 kilometres from the outer coast the original mountains may still remain unaltered below the surface of the continental shelf, if the general mountain slope had originally a uniform inclination *x' y'*.

The steepness of the continental slope off Vesteraalen and Senjen (see above p. 39) is also conclusive evidence that, at least at this place, the continental shelf has not been exclusively built up by loose materials, for submarine declivities of such great angles can only be formed by solid rocks.

The transverse sections of the continental shelf and the land support, on the whole, the above views. In the sections on Pls. XII—XVII the highest peaks on the land near the landward continuations of the lines of the sections, have been introduced at their proper distances from the coast; the vertical scale is exaggerated 50 times. It is seen that the highest peaks in each section reach, as a rule, fairly uniform heights indicating a very regular slope, the *land-slope*, from the highest axis of the land towards the sea[1]. The sections demonstrate clearly that along the whole coast from Søndmør to Finmarken, not only the coast platform but also the inner part of the continental shelf forms a deep and distinct horizontal incision in the general land-slope, indicated by the mountain peaks, and this seems to prove that not only the coast platform but also some part of the continental shelf has been cut by marine denudation.

But the relation between the angle of the land-slope and the width of the continental shelf differs much in the several parts of the coast. In Senjen, Vesteraalen, and Lofoten (Sections 11—18, Pls. XII—XIII) the slope indicated by the mountain peaks cuts the sea-surface beyond the edge of the continental shelf and beyond the continental slope which is very much steeper. In Nordland (Sections 20—27) the plane of the land-slope cuts the continental shelf generally a good distance inside its edge, and passes inside the continental slope which is on the whole not much steeper. Off the Romsdalen coast (Sections 29—31) the plane of the land-slope cuts the continental shelf inside its edge, but it cuts also the continental slope above the oceanic floor, and at depths of about 700 to 1000 m. The con-

[1] Prof. Vogt (*l. c.* pp. 12—14) has determined the mean angle of the land-slope in Helgeland to 40′, or 1 in 86, while in the Romsdal region it is about 1°, or 1 in 57.

tinental slope is appreciably steeper than the land-slope. If we assume that the coast of Nordland is now submerged much deeper than it was during long remote geological periods, and that the land-slope before the submergence, was fairly uniform far below present sea-level, the above facts must naturally prove that the continental shelf has to a great extent been built up by waste. The assumption of such a great submergence of the Norwegian coast is, however, very doubtful. We do not know what the original land-slope of the coast may have been, but we know that even the highest present day mountains of Nordland and probably also those of Romsdalen, and Lofoten-Vesteraalen have been worn down thousands of feet (at least 1000 m. and probably much more) during the time elapsed after the original mountain-folding (see p. 57); while on the sea-bottom there is practically no erosion below a certain depth. Although the shore-line may have oscillated much, vertically, during previous geological periods, it must nevertheless have had a mean position, near to which it has stood during the greater part of the time — after the formation of the Norwegian mountain system — during which the above enormous subaerial erosion of the mountains took place; and it is obvious that a great, though uneven platform must have remained below this mean level of the shore-line, while the land-slope was gradually being cut back by the erosion (cf. fig. 2, p. 134). If we assume that the above mean level of the shore-line was not much below present sea-level, which does not seem improbable, we are also obliged to assume that *the above ancient platform forms, to a great extent, the underlying ground of the present continental shelf.* The angle of the present land-slope may also depend on the different intensity of the erosion at different distances from the outher coast. I consider it probable that the drowned plain of the Barents Murman Sea has also been formed largely in the above manner. That oscillations of the shore-line about a mean position actually have occurred during long periods in this region, seems to be proved by the Jurassic and Pre-Cretaceous shallow-water layers intermixed with layers of basalt on Franz Josef Land [1] and on King Charles Land.

The fact that rocks have been found at several places of the Norwegian continental shelf, even on the very edge, and on the continental slope, might seem to support the above view; but it must be remembered that isolated records of rock are hardly quite trustworthy, for they only mean that the lead brought up no bottom sample; it may have struck stones, too big to adhere to the tallow of the lead, or the stones adhering, may have been washed off on the way up. Where, however, rocks are recorded from several places within a small area, it seems more probable that rocks actually were present. This is for instance the case along the edge of the continental shelf between 65° 10′ and 66° N. Lat. (Sections 23 and 24, Pl. XV), a rocky ridge forming the salience which is conspicuous in Section 23, possibly rises above the general floor in this region. In very nearly the same region traces of an ancient longitudinal valley may probably also be seen inside this ridge, near the edge of the shelf (see p. 55, and Pl. XI).

It was pointed out above that even *the outer parts of the continental shelf* are probably largely composed of rocks at no great distance below the surface; but, especially where the shelf is broad, it has apparently also to a great extent, been built up by terrigenous waste, a great part of which is glacial drift[2]. Excluding the irregularities caused by the seaward extension

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[1] Cf. POMPECKJ, *ante* vol. I, No. 2.

[2] The coarse materials — coarse sand, gravel, shingles, and stones — which generally cover the floor of the Norwegian continental shelf, where it does not lie very deep, cannot have been transported to their present position by the movements of the sea-water, but must have been carried by glaciers. To mention an example, it is impossible that the sand, shingles, and stones now composing the floor of the Halten Bank

of the Lofoten-Vesteraalen Archæan-Gabbro region, and also to a smaller extent by the Romsdalen Archæan region, the edge as also the declivity of the Norwegian continental shelf, between 62° 40′ and 70° N. Lat., on the whole, runs fairly parallel to the trend of the Norwegian mountain system (as VOGT has already pointed out, *l. c.* p. 5) and also to the trend of the coast. The axis of the Norwegian mountain system has a distinct concave bend, the strike of its southern part, south of 64° N. Lat., trending more westward than farther north, and it is probably continued in a south-westerly direction across the North Sea in the Scotch mountain system[1]. The edge of the continental shelf follows on the whole the same concave curve from the Færoe-Shetland channel to 70° N. Lat., but off Helgeland, in Norway, it edges off seawards in the form of a wide convex curve. Let us for a while suppose that the land originally followed a fairly regular curved line from the Vest Fjord over the bank off Bindalen, the Halten Bank (both of which are probably built of Archæan rocks), the Bank off Smølen, to the banks off the Romsdalen coast, then it might also seem an obvious conclusion that the trend of the original continental declivity, somewhere inside the edge of the present shelf, ran fairly parallel to the same line; but if so, the greater part of the present continental shelf and the continental slope which is beyond this original line, has probably been built up by waste. This is, however, a bold conclusion, for, as pointed out on p. 46 and pp. 53—54, it is not only the edge of the shelf which in this region trends seawards, but the sea outside is also comparatively shallow, the gentle declivity of the shelf forms, as it were, a fan projecting, with gentle slope, far into the deep Norwegian Sea, and we should thus be obliged to assume that the whole of this enormous 'fan' was built up by waste to a thickness of 1000 m. or more. After all a theory such as this, is not altogether absurd; we know *e. g.* that the mountains of Nordland have been denuded at least 1000 m. after the

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(Sections 25 and 26, Pls, XV—XVI), can have been carried by currents across the deep and broad, submarine longitudinal fjords between the bank and the coast, if these fjords existed before the above materials were deposited, as they obviously did (see above). There are hardly any other agents than glaciers that have the necessary transporting capacity; ice-bergs and drifting sea-ice may transport coarse materials, but hardly sufficient to fill up, within a reasonable time, the deep fjords and valleys of the outer parts of the shelf, or to build up the whole shelf.

[1] Cf. ED. SUESS, 'Antlitz der Erde', vol. II, 1888, p. 100.

great mountain folds were formed, and the enormous quantities of waste thus arising have been deposited somewhere on the sea-bottom. And again when the great longitudinal valleys of the continental shelf were first eroded, the land once stood much higher, or the sea-level was lower, and two or three great river-systems (the Trondhjem-Folden, the Helgeland, and the Vest Fjord systems) draining the whole area between Romsdalen and Vesteraalen (the rivers through the above longitudinal valleys belonged to these systems), carried their waste into the sea off the Nordland coast, which was then much farther out to sea, and during these remote periods the *Vøring Plateau* (p. 54) was perhaps formed. It is also probable that during the great Ice Age the inland-ice extended far out into this shallow sea where the coast was relatively low and the ice-movement not impeded by high coast mountains to the same extent as in Lofoten-Vesteraalen and the Romsdalen region. The inland-ice was evidently to a great extent forced south-westward into the Vest Fjord by the Lofoten mountain ridge, while from the south the inland-ice had an easy access over the low land in the Trondhjem region and through the great Trondhjem-Folden Submarine Fjord. Much more glacial drift was thus probably carried into the sea in this region than north and south of it. It is therefore possible that the outer part of the continental shelf between 64° and 67° N. Lat. is largely built up by river-waste deposited during pre-glacial times and by glacial drift during the glacial periods. This view is apparently supported by the fact that the plane of the mean land-slope cuts the shelf far inside the edge, and passes inside the continental slope (see above p. 152), the latter is also steeper in its lower part (below 800 m.) than further up (see p. 53) which is above mentioned as a characteristic feature of waste shelves (p. 145). But there is the difficulty that along the edge of the shelf just where it is broadest, between 65° 20′ and 66° N. Lat., a rocky ridge probably rises above its general floor (see above p. 153); further, inside this ridge there are traces of a longitudinal valley (between 65° 20′ and 66° 20′ N. Lat.), which might indicate ancient mountain folding of the underlying ground. The ridge might possibly be a terminal moraine, and the many records of rocks on its surface could be ascribed to boulders struck by the lead. The longitudinal direction of the drowned valley might also have been caused in part by the moraine; but it is striking how the direction runs exactly parallel to the mean longitudinal direction of the coast;

and besides, there are indications of the same longitudinal direction in the outer and inner branches of this valley (see the 400 m. contour) which would lead to the assumption of a series of moraines. We have therefore, to accept the probability of a rocky ridge, at the edge of the shelf, as well as rocky ground at no very great distance below the surface in the outer part of this shelf at the place where it is broadest, but also comparatively deep[1].

The narrow parts of the continental shelf off Søndmør-Romsdalen and off Vesteraalen are obviously built up by loose materials to a much less extent than is the shelf off Nordland; but considering that the traces of the submarine fjords are almost entirely obliterated in their outer parts, it seems probable that even in these regions much waste has aided in the formation of the present shelf, if we do not accept the theory that the hollows of the submarine fjords are, to their full extent, true rock basins, carved by glaciers in the level rocky ground of the shelf.

The barriers or sills of the fjords and of the submarine fjords.

Our view of the origin of the Norwegian continental shelf must be greatly influenced by our view of the origin of the fjords, and by our explanation of the general and conspicuous fact that, in Norway like other formerly glaciated lands, there are much greater depths in the fjords inside the outer coast-line than on the continental shelf, — the fjords and their submarine prolongations form as it were, a series of long deep troughs scooped out inside and in the inner part of the flat platform of the shelf, and very often disappearing before they reach its outer edge; the submarine channels of some fjords even disappear at once, or are at least difficult to trace, on the sea-bottom outside the coast, *e. g.* the deep Sogne Fjord, the Nord Fjord, the Romsdal Fjord. Most submarine fjords on the shelf are deepest near the coast and if they do not disappear seawards (*e. g.* like the Bredsundsdyb, and the submarine fjords or hollows off Lofoten), their deep hollows are at least separated by barriers from the deep ocean, *e. g.* the deep And Fjord and the Malangen Submarine Fjord (69° 10′—50′ N. Lat., Pl. XI).

Are the troughs of the fjords true rock basins? There are so many weighty evidences of the genetic relation between the typical present sculpturing of the fjord-regions and the ice ages, that it seems to me impossible to deny that the glacial erosion must have been of great importance for the formatien of the present fjords. An important evidence has been brought forward by Prof. HELLAND[2], when he points out that the average

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[1] After the above had gone to press, Dr. JOHAN HJORT has kindly informed me that during numerous fishery investigations made this summer (1903) it was found that there was hard rock at several places on the above ridge. I may instance that in about 65° 34′ N. Lat. and 6° E. Long., and in about 65° 50′ N. Lat. and 6° 20′ E. Long., the bottom was partly sand and big stones and partly rock, at depths of between 300 and 370 m.; and the fishing lines very often stuck to the bottom in a way as they generally do on hard rock.

[2] AMUND HELLAND, 'Tromsø Amt', *Norges Land og Folk*, vol. XIX, Christiania, 1899, Part 1, pp. 66—69; *Arch. f. Math. og Naturvid.*, Christiania, 1876, p. 387.

height, at which cirques occur, decreases northward with the snow-line, in northern Norway numerous cirques are found at present sea-level, and there is a special type of fjords which may be called *cirque-fjords* and *cul-de-sac-fjords.* These fjords, which may be short or long, terminate in a *cul-de-sac* with high steep mountain-walls, and are not directly continued inland by valleys. Fjords of this type are very common in northern Norway where the glaciers may still reach sea-level, whilst they have not been observed farther south. They cannot possibly be submerged regular river-valleys, but their cirque formation must be due to comparatively recent glacial erosion. Although thus there can be little doubt about the glacial erosion of the fjords, it is very difficult to decide to which extent the fjords have been carved by the glaciers, and whether, for instance, their deep troughs are true rock basins entirely excavated by glaciers in the rocky ground. If so we would get a simple explanation why so many deep fjords have no or at least very shallow prolongations on the level platform of the continental shelf, beyond the outer coast line. This question cannot be decided by direct observations, as the ground is under the sea; the lakes on land are, however, probably formed in a similar manner as the fjords, and they are easier to examine.

There is as AMUND HELLAND has proved long ago[1], little doubt that, quite irrespective of what their prime origin may have been, the present sculpturing of most Norwegian lake basins, which much resemble the fjord basins, is due to glacial erosion; a great many of them are evidently, more or less, true rock basins, which have been hollowed out and widened, at least to some extent, in solid rock to form troughs which narrow and become shallower towards the outlet[2]. The majority of Norwegian lakes, and especially the deepest ones, are, however, also barred at their outlets by great terminal moraines[3] and their depths have thus at any rate been increased, even though they may be rock basins to some extent. The depths of the known true rock basins, *e. g.* the Langvand, are not very great, and do not by far approach those of the fjord basins; but the glacial erosion has probably been much greater in the fjord region than farther inland, and we may therefore expect the true rock basins of the lakes to be shallower than those of the fjords, although the difference seems too great to be merely thus explained. To judge from what we can directly observe in the lakes, it is probable that the troughs of the fjords are to some extent true rock basins, which, however, are also barred by moraines and by sills composed of waste and glacial detritus[4].

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[1] AMUND HELLAND, 'Om Dannelsen af Fjordene, Fjorddalene, Indsøerne og Havbankerne', *Öfversigt Kungl. Vet.-Akad. Förh.,* Stockholm, 1875, No. 4. See also, *Arch. for Math. og Naturvid.*, Christiania 1876, and *Quat. Journ. of Geol. Soc.*, London, 1877, p. 142.

[2] *Langvand* near *Sulitelma* is, according to the description by OTTO NORDENSKIÖLD (*Bull. of Geol. Inst. Upsala*, No. 8, vol. IV, Part II, 1899), a good example of a true rock basin. The lake is 11 kilometres and 84 m. deep; at the outlet, in a narrow pass, there is only rock *in situ*, no gravel or sand terraces. The lake is on all sides surrounded by high mountains and cannot formerly have had any other outlet. No indications of faults or dislocations have been observed. The lake is

61 m. deep 3 kilometres from the outlet, the slope of the bottom being 1 in 50
84 „ „ 8 „ „ „ „ „ „ „ „ „ 1 „ 100.

These slopes of the bottom are too great to be explained by the post-glacial oblique upheaval of the land. There seems to be no other explanation than erosion in solid rocks. In many other mountain lakes, *e. g.* Bygdin, Gjendin, similar conditions may certainly be observed.

[3] See AMUND HELLAND, 'Om Beliggenheden af Moræner og Terrasser foran mange Indsøer, *Öfvers. Kungl. Vet.-Akad. Förh.*, Stockholm, 1875, No. 1.

[4] AMUND HELLAND has directly proved the occurrence of masses of moraine matter under the shallow sea off the mouths of several Norwegian fjords, see *Öfvers. Kungl. Vet.-Akad. Förh.*, 1875, No. 4, pp. 28—30, and *Quat. Journ. Geol. Soc.*, 1877, p. 175.

Whatever point of view we take it seems to me that we are obliged to assume that, the *barriers of the fjords and a great part of the continental shelf outside must have been built up by waste and glacial drift to a great extent*, for — either the fjords have been more or less carved by the glaciers, in which case the enormous quantity of waste thus arising as well as that carried from the land inside, must have been deposited somewhere at the terminal margin of the glaciers, near or outside the mouths of the fjords, and must have aided in forming the barriers, — or else the fjords have not been carved by glaciers, in which case they must be ancient river valleys sloping seawards, the outer parts of which have been filled up by waste, chiefly moraines and glacial drift. A channel more than 1300 m. deep must then, for instance, have passed from the Sogne Fjord towards the floor of the Norwegian Sea, and must afterwards have been almost entirely filled up for a great distance, which, however, is hardly probable. It is obvious that inland-ices have a strong tendency to carry all waste, which formerly filled up the fjords and covered the land surface, as far into the sea as they reached during their greatest extension. This process repeated during several glacial epochs, or during several oscillations of the inland-ice, would naturally tend to the formation of a shallow sea outside the fjords.

A splendid example of moraines barring the fjords is the great Svelvik moraine across the Drammen Fjord, which was formed by a glacier coming from a very limited area, as pointed out by BRØGGER (see above p. 65, footnote), and is nevertheless 190 m. high from base to summit. Outside this moraine the fjord is evidently largely filled up by deposits of glacial detritus. The frequent occurrence, in the submarine fjords on the continental shelf, of series of hollows descending very nearly *to the same depth* (see Pl. XI, and Pl. XXI, Sections *A*, *D*, *E*) might indicate that the hollows once formed a continuous valley which has been divided by transverse ridges of loose material; this would at least, according to my view, be a more natural explanation than to assume that all these hollows are true rock basins, carved by a succession of local glacial erosions, for I do not understand how this could occur in a perfectly level region like the coast platform. On land we may find succession of lakes, but they are very often barred by moraines, and are generally situated among mountains where there are conditions for local differences of erosion.

I do not consider it probable that the Norwegian fjords have been carved and deepened by glacial erosion to the extreme extent as some glacialists seem prone to believe. The principal topographical features of the fjord regions were, according to my view, developed already in pre-glacial times, and the existence and configuration of the great longitudinal valleys and fjords of the land surface as well as of the continental shelf is, as mentioned above (p. 151), a weighty evidence: they must owe their prime origin to the erosion of running water, and not to glacial erosion, and some of them have hardly even been much deepened by the glaciers, especially not the submarine longitudinal fjords of the flat continental shelf, for else they would certainly at present have had a more radial direction (*cf.* above pp. 57—58). Let us take as an example, the Trondhjem-Folden Submarine Fjord (see above p. 54 and Pl. XI): it does not seem conceivable that this system of drowned longitudinal and transverse valleys could have had its precent remarkable configuration if it had been chiefly sculptured by glaciers; and for instance, the deep longitudinal channel between the Fro Islands and the Halten Bank, extending from about 64° N. Lat. and 8° E. Long. towards Vikten, along a distance of 150 kilometres cannot even have been very much deepened by glacial erosion; for the glacier, which should have excavated it, must have followed the direction of the valley, and must consequently have advanced nearly parallel to the coast, and parallel to the general margin of the inland-ice, for a concider-able distance through a low and flat region. We would then be obliged to assume that the great glacier of the inland-ice advanced across the longitudinal ridge between the Fro Islands and Vikten, and by meeting the hard Archæan rocks of the Halten Bank rising to within 100 m. of present sea-level, this great glacier was divided into two branches, one moving towards south-west between the Halten Bank and the Fro Islands, and the other branch moving towards north and north-north-west between Vikten and the Halten Bank. The contours of the Halten Bank might seem to indicate that it

has actually been sculptured by glaciers as mentioned above, for the contours — *e. g.* those of 200 and 300 m. — are much smoother on the inner than on the outer side of the bank. The highest part of the bank (102 m. below present sea-level) is about 350 m. above the deepest hollow off Vikten, and about 400 m. above the bottom of the deepest hollow off the Fro Islands, but it is only 200 m. above the broad sill separating this hollow from the deep ocean, and it seems improbable that a bank projecting only this much, or even less, above the surrounding flat region should have been able to stop and deflect the course of the great inland-ice as pointed out above. It seems therefore probable that the above sill is at least to some extent built up by loose material, and that the drowned longitudinal valley south of the Halten Bank has had a deeper comunication than now with the deep ocean, and that it consequently can only to a limited extent have been deepened by the glaciers. And besides, if the glacier of the inland-ice had been able to excavate this deep and long longitudinal valley, it seems probable that it would have been able to wear down the ridge between the Fro Islands and Vikten to a much greater extent, and would not only have carved the narrow transverse valley now connecting the deep longitudinal fjord inside the Fro Islands with the drowned longitudinal fjord outside them. In the latter fjord there are the following deep hollows in succession from off Vikten towards SW: 414 m., 452 m., 467 m., 471 m., and 514 m. (off the Fro Islands). These hollows are separated by the following ridges 362 m., 362 m., 414 m., 412 m.; and by a sill of 305 m. the deepest hollow is separated from the deep ocean. It is, according to my view, probable that, these ridges and sills have to a great extent been built up by loose materials (glacial drift), and that the hollows indicate the original seaward slope of the bottom of the valley, although the latter may have been somewhat deepened by glacial erosion.

The Vardø-Murman Channel passing along the Finmarken coast (see pp. 28, 31, and Pls. II and XI, and also Pl. XXI, Sect. *A*), is also a good example of a submarine fjord which cannot have been very much deepened by glacial erosion, for the glaciers must chiefly have moved athwart the fjord, and cannot possibly have excavated the winding course of this long and narrow channel in the flat region.

The assumption that the present fjords and their deep troughs have been carved in the rocky ground exclusively by glacial erosion during the ice ages, and did not previously traverse the continental shelf, also meets with the difficulty that in this case the shelf, which is chiefly a pre-glacial structure, must have been cut by marine denudation in solid rock along a but slightly dissected coast, and this seems hardly possible, according to what has been said above (pp. 105, 133).

If we assume that the glaciers have been able to excavate the trough of the Sogne Fjord, for instance, to a depth of about 1100 m. below the level of its sill at the mouth, it seems natural to expect that they would also have excavated the side-slopes and widened the troughs much nore in the inner parts of the fjords than near their mouths. Although the fjords sometimes (*e. g.* Nord Fjord) actually are narrower near their mouths than farther inland, they are on the whole much less so than the above assumption would make probable[1].

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[1] The great Godthaab Fjord (with the Ameralik Fjord) on the west coast of Greenland (64° 20′ N. Lat.) is probably a magnificent example of a great and wide fjord-system which narrows much and is nearly closed by many islands and skerries at the mouth (Pl. VI, fig. 4). The great Scoresby Fjord on the Greenland East Coast may also be mentioned, but there are peculiar geological conditions as pointed out by O. Nordenskiöld (see p. 211). The greatest depths of these Greenland Fjords are not known, but they are probably very deep, depths of 600 and 800 m. have been observed. On Iceland there are examples of fjords which are undoubtedly true rock basins. Thoroddsen mentions that some of the deepest fjords on Bardastránd are closed at the mouths by series of ice-worn skerries, but the greatest known depths of these fjords are only 170 m. He mentions also deep lakes (Vatnsfjördur on Bardastránd, Skorradalsvatn,

The following consideration may also be of some importance in this connection. Many facts speak in favour of the theory that the post-glacial upheaval of Norway is an isostatic movement, but this theory does not harmonize with the assumption that the fjord basins have been recently carved entirely by glaciers, for the enormous quantities of rock which should thus have been removed during the glacial periods would have produced an upheaval, which cannot have been uniform along the coast, and must have been considerable at some places, for instance near the Sogne Fjord where several thousand metres of rock were removed. The upheaval thus produced would naturally also have been greater in the fjord region than farther inland. There are, however, no certain evidences of such differences. We have seen above (p. 128) that the coast platform has a fairly uniform level, at least its lower edge, along the whole coast from Lindesnes to Sørø in Finmarken, although the post-glacial upheaval of the land exhibits regular variations.

It is a peculiar fact that the submarine fjords are much deeper and more distinctly traceable for longer distances on the most submerged parts of the Norwegian continental shelf — *e. g.* off the coast between 64° and 67° N. Lat. and off the Finmarken coast north of 70° N. Lat. — *than on its higher parts, off Søndmør-Romsdalen and off Lofoten-Vesteraalen,* where the submarine fjords seem to be almost obliterated. Why, for instance, have not the deep and great fjords of Sogn, Søndmør and Romsdalen — *e. g.* Sogne Fjord, Nord Fjord, Stor Fjord, Romsdal Fjord — deep submarine prolongations outside their present mouths to the same extent as the much smaller fjords of Helgeland, and the fjords of Finmarken? The most natural explanation appears to me to be that the submarine channels of the Søndmør-Romsdalen Shelf and the Lofoten-Vesteraalen Shelf are filled up by loose materials to a much greater extent than are those of the lower parts of the Norwegian continental shelf. This view is also supported by the fact that in Nordland (p. 59) and Finmarken there is much less difference between the depths of the fjords and those of the deepest hollows of the submarine channels outside, than for instance in Romsdalen, Søndmør, and Sogn. It is possible, that the submarine fjords in the high, Archæan and Gabbro regions of the continental shelf (off Søndmør-Romsdalen and Lofoten-Vesteraalen) may have been much narrower, and easier to fill up than were the broader fjords of the lower regions of the shelf, greatly composed of weaker rocks. In the Trondhjem district, Nordland, and Finmarken the land near the coast is also on the whole, lower than in Lofoten-Vesteraalen and in Søndmør-Romsdalen, and in the lower regions with a broader continental shelf outside, the inland-ice, being less stopped by high coast mountains, may have extended much farther out to sea. The glacial drift was therefore carried farther from the coast into deeper water, and was spread over a greater area, than was the case off the high, more mountainous coasts where the continental shelf was narrow, where the margin of the inland ice probably oscillated less, and did not extend far beyond the present coast. In the latter region the glacial drift settled in a shallower sea near the coast, in doing which it aided in the building of a well defined continental shelf, and in obliterating the submarine fjords.

The *marine denudation,* after the glacial erosion, may have been of some slight importance in filling up the submarine channels outside the coast to their present-day state; especially on the higher parts of the continental shelf, the wave-action may have swept away glacial drift left on protuberant parts near sea-level, into the deeper water of the submarine fjords.

The inner parts of the fjords may possibly also have become relatively somewhat deeper through the land having been more depressed by the weight of the ice-sheet inland

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Lagarfljót) which are barred by ice-worn ridges of basalt (see *Geografisk Tidsskrift,* Copenhagen, vol. XVI, 1901—1902. p. 70). HELLAND has already pointed out that the bathymetrical features of the Icelandic fjords resemble to some extent those of the Norwegian fjords (see A. HELLAND, 'Færøernes Geologi', 1881, reprint p. 25, and 'Islands Geologi', 1882, reprint p. 16.

than near the outer coast, possibly it has not again risen to its original level; in any case it is of little importance compared with the great differences of depth between the fjord-troughs and their sills.

Summary. According to what has been said above, the history of formation of the fjords and their sills may briefly be: The great topographical features of the fjords and the valleys of the land had been already developed by subaerial erosion in pre-glacial times; for some period the land stood then higher than it does now; during the glacial periods the fjords were much deepened, especially in their inner parts, and got their present sculpturing by glacial erosion, but at the same time great quantities of waste and glacial drift were deposited on the sea-bottom outside the coast and in the outer parts of the fjords, where the margin of the glaciers probably remained fairly stationary for long periods (cf. what has been said above, pp. 64—66, of the Norwegian Submarine Channel). Thus the submarine prolongations of the fjords were more or less filled up and the difference between the depths of the inner and outer parts of the fjords were increased. During periods of relatively rapid retreat of the ice margin, there was no opportunity for the submerged fjords to be filled up at a particular place, while during pauses or oscillations in the retreat new barriers or moraines were formed. The final result was that the fjords became deepest in their inner parts because the glacial erosion was there most effective, and it began early and ended late — and because they were there less filled up by glacial drift than farther out, and all pre-glacial and inter-glacial sediments had been carried seawards. The series of great moraines and the deposits of glacial detritus in the region of the Christiania Fjord prove that the last ice-sheet actually retreated in the way described above.

Although the barriers of the submarine fjords are obviously peculiar glacial features which chiefly occur inside regions formerly covered by glaciers, similar features may also occur outside the boundaries of the ancient inland-ice. I may instance the *Hurd Deep* in the English Channel; this hollow is 174 m. (see above p. 94) while the sea outside is only 85 m. deep. It seems probable that the drowned valley of the ancient river once draining the region of the English Channel, has been largely filled up by waste, but the deposition of the waste may have been reduced over the present Hurd Deep by rapid currents, whilst the currents have not been so rapid in the broader channel farther sea-wards. The occurrence of gravel on the sea-bottom outside the Deep may, however, seem to reduce the probability of this theory, as very strong currents would be necessary to transport the gravel. It is also conceivable that during a former period when the shore line had a lower position, when the Straits of Dover were closed and the English Channel was a bay, coast banks of sand and gravel were formed outside the Hurd Deep. It seems also possible that there are several hollows in the *Fosse de Cape Breton* closed by barriers, but the soundings are not numerous enough to make it possible to say anything with certainty. On the whole it may be admitted that barriers are extremely rare in the drowned valleys outside the

formerly glaciated regions, and this circumstance is in good harmony with the view that these drowned valleys were actually formed by subaerial erosion.

Do the bathymetrical features of the submarine fjords indicate that the Norwegian continental shelf has been elevated above sea-level after its formation?

It has been pointed out above, that the great features of the present valleys and fjords of the Norwegian land-surface as well as of the continental shelf, were probably carved by atmospheric erosion in pre-glacial times, to a considerable extent even before the formation of the continental shelf, which, itself must to some extent have been cut by marine denudation and subaerial erosion along a previously much dissected coast. Afterwards the fjords have been much deepened — to a great extent after the formation of the continental shelf — by the glaciers which gave them their present sculpturing, and filled up their outer portions.

On pp. 48—49 and 59 I have pointed out that in all great submarine fjords, on the continental shelf, from the Bear-Island Channel to the Norwegian Channel, there is a great similarity in the greatest depths, as well as in the mean depths of the outer portions, near their mouths, and moreover, that these depths may indicate a base-level of erosion during some previous period of elevation (*ante* p. 48). This view is supported by the fact that the great submarine fjords are hardly traceable along the continental slope beyond the 500 m. contour (*ante* p. 60).

A simple explanation of the above fact without assuming a recent elevation of the continental shelf, would be that the relatively shallow outer portions of the submarine fjords are remnants of the ancient valleys carved by atmospheric erosion in pre-glacial times, before the continental shelf had been formed; the land may then during long periods have stood about 500 or 550 m. relatively higher than now — and the great valleys of Norway were worn down to about the same base-level of erosion as the deep submarine fjords of Iceland, Greenland, and Canada (see pp. 81, 89, 97) as well as also the submarine ridges extending from Scotland to the Færoes Iceland, Greenland, and Baffin Land (pp. 50, 74, 83, 84, 89). Afterwards the coast has been submerged, and the deep troughs of the Norwegian fjords

have in this case been carved later by submarine glacial erosion[1]. When these troughs were eroded, the outer shallower portions of the submarine fjords must necessarily have been filled up by glacial drift; but they may later have been more or less re-opened by a new advance of the ice-sheet, and the mouths may thus have approached their original uniform depths. It will be seen that the above explanation avoids the necessity of a recent elevation of the continental shelf; and I must admit that it is plausible, in spite of the fact that it involves several difficulties.

It seems to me, however, to be a more probable explanation that the continental shelf has comparatively recently been elevated above the sea. The fjords may then have been re-opened towards a base-level by subaerial erosion, and if the shelf was not covered by ice, the inner hollows were transformed into lakes. But it is perhaps still more probable that the outer parts of the fjords were then levelled to a certain depth below sea-level, by the glacial detritus of the inland-ice extending into their inner parts[2]. It was pointed out

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[1] It seems to be a not uncommon belief that glacial erosion should be less effective under sea-level than above it, because the pressure of the ice on the underlying ground should be greater in the latter case. This is not correct, the pressure on the ground is the same in both cases, and as long as the glacier is not actually lifted from the bottom by its buoyancy in water, the mechanical effect of the moving ice on the bottom must be the same whether the glacier be more or less submerged, provided that the rate of its movement be not altered. It is therefore an unfortunate expression when, for instance, it is said above, on p. 28, in connection with submarine glacial erosion, that "the weight of the ice over the bottom of the channel would moreover be reduced by its buoyancy in 400 m. of sea-water". The pressure of the water when a glacier or an inland-ice is more or less submerged, will, however, tend to reduce the rate of glacial motion, as it counteracts the internal outward pressure in the glacial mass. This is, however, of little importance in the excavation of the throughs of the fjords, where the sills nearly reach sea-level, and where the additional pressure of the water above the sills is comparatively insignificant. These troughs would equally easily be eroded above or below water-level. It is also very probable that the pressure of the water if an inland-ice be somewhat submerged, will tend to increase the thickness of the ice, because the outflow of glaciers must be in a certain proportion to the snowfall on the surface of the inland-ice.

It is not probable that the friction between the ice and the ground is on the whole much influenced by changes in the pressure; if anything it might rather seem possible that a high pressure might reduce this friction, as it makes the ice more viscous. But we know still too little of the real nature of the erosive effect of the glaciers upon the underlying ground, to be able to determine what importance the pressure has in this respect.

[2] It is clear that in this case the shelf has not been elevated as much as 400 or 500 m. for on the exposed outer coast of the shelf the submarine fjords could only be filled up to a certain depth below sea-level, and this depth would vary somewhat, according to the effect of the wave-action; it may have been smaller at the mouth of the Norwegian Channel than farther north.

on p. 49, that the general floor of the Smølen Submarine Fjord[1] is nearly at the same level as the barriers between the hollows of the other submarine fjords, which, to a very great extent, have depths of between 250 and 300 m.; I may instance the fjords mentioned in the table on p. 49, and also the three submarine fjords mentioned on p. 40 — the And Fjord, the Malangen Submarine Fjord, and the fjord in 70° 10′ N. Lat., — which have barriers at 260 and 255 m. below sea-level. It may be that this and similar facts indicate that there have been several pauses in the recent vertical oscillations of the shore-line of the continental shelf. It is, however, worthy of mention, that although there is a great similarity of depth in the outer portions of the great submarine fjords of Norway, Iceland, Greenland, Canada, and perhaps even the Færoes, which might indicate recent universal oscillations of the shore-line, this is not the case in Scotland and England, where the submarine fjords are much shallower. It seems difficult to explain this if the continental shelf in this region has had a similar recent elevation. It might, however, be possible that the fjords there have never been very deep and have not been re-opened by glaciers to the same extent.

That the continental shelf of the northern lands has resently been near or above sea-level is also indicated by the fact that numerous dead shells of shallow-water moluscs have been found at several places on the shelf at depths of between 100 and 200 m. G. O. Sars[2] found such shells (*Mya truncata, Saxicava rugosa, Venus casina*) at depths of about 100 m. on *Storeggen*, and also great quantities of small water-worn pebbles; Spotswood Green[3] at about 180 m. on the Rockall Bank, Godwin Austen[4] (*Patella vulgata, Turbo, Littorina*) at depths of between 140 and 180 m. far out to sea south-west of Ireland, and A. S. Jensen[5] of the Danish Ingolf Expedition, 1898, found dead shallow-water shells at similar and even greater depths off the Færoes, etc. The occurence of dead shells of shallow-water moluscs at relatively great depths on the continental shelf, may, as A. C. Johansen has

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[1] It ought perhaps to be observed that the Smølen Submarine Fjord is situated in the high Archæan region of the continental shelf near Romsdalen.

[2] G. O. Sars, *Forhandl. i Videnskabs-Selskabet, Christiania*, 1872.

[3] W. Spotswood Green, *Trans. Royal Irish Academy*, vol. XXXI, part III, p. 45.

[4] Godwin Austen, *Quat. Journ. Geol. Soc.*, vol. V, 1850, p. 69.

[5] A. S. Jensen, *Vidensk. Medd. Naturh. Forening*, Copenhagen, 1900 and 1902.

pointed out, be no conclusive evidence that the sea-bottom where they are now found, has once been elevated near sea-level, for the dead shells may have been transported by ice, by animals, by floating sea-weed, and possibly even by water movements, and the vertical range of the moluscs found may in most cases actually exceed the depths at which they were found[1], although they certainly never live in great quantities so deep; but when relatively large numbers of the dead littoral shells are found together with quantities of shingle and pebbles wich have a distinct appearance of having been water-worn on a shore, as is the case on Storeggen as well as south-west of Ireland, the probability of a previous elevation of the sea-bottom (or a lowering of the sea-level) is certainly much increased, and still more so when we see how well these facts harmonize with the above evidence of the submarine fjords. It thus seems higly probable that the continental shelf of Norway as well as of other northern lands has been elevated into dry land after its formation. The occurence of dead littoral shells as well as water-worn shingle and pebbles on the surface of the shelf also indicates that the surface of the shelf cannot have been covered by much deposit of sediments after the shelf was last submerged[2].

Summary. The history of formation of the Norwegian continental shelf. According to what has been said on the preceding pages I believe that this history may be summarized as follows: The shore-line has oscillated much, the area of the continental shelf was during long pre-glacial periods dry land, and was much dissected, chiefly by atmospheric erosion; the great main features of the depressions of the shelf were then developed: the valleys, carved by rivers, had along the greater part of the coast a conspicuous tendency to follow two different directions: one longitudinal direction, following the mountain folds running more or less parallel to the coast, and one transverse direction nearly at right angle to the former. During periods of relatively high elevation of the land in remote geological periods the now sub-

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[1] A. C. JOHANSEN, 'On the hypotheses on the sinking of sea-beds based on the occurrence of dead shallow-water shells at great depths in the sea', *Vidensk. Medd. Naturh. Forening*, Copenhagen, 1902.

[2] AMUND HELLAND has long ago maintained that this was the case off the mouths of the Norwegian fjords, see: 'Om Dannelsen af Fjordene, Fjorddalene, Indsøerne og Havbankerne'. *Öfversigt Kungl. Vet.-Akad. Förhandl.*, Stockholm, 1875, No. 4.

merged longitudinal fjords of the shelf were eroded perhaps to a base-level about 500 or 600 m. below present sea-level. The great general denudation of the land of more than 1000 m. after the formation of the Norwegian mountain system, tendend to lower the outer part of the land to the mean level of the shore-line. When the dissected land was submerged an intersected coast with deep submarine fjords, arose, which was comparatively easily cut back by the conjoint action of marine denudation and subaerial erosion; in this way an imperfect and uneven coast platform was formed, sculptured by broad longitudinal and narrower transverse submarine valleys. But those parts of the coast which were greatly built up by weaker rocks, *e. g.* Nordland and Finmarken, were during the oscillations of the shore-line cut down to lower levels than the Archæan regions of the coast, *e. g.* Søndmør-Romsdalen, Lofoten-Vesteraalen. The ancient coast platform or shelf thus formed, has now been much filled up by marine deposits and glacial drift, especially on its outer parts; and outside it, waste has also been deposited and the shelf made broader. The submerged valleys of the shelf have probably several times been more or less re-opened by glaciers and during periods of elevation by atmospheric erosion. The glaciers have prevented the inner parts of the submerged valleys, longitudinal and transverse valleys, from being re-filled to the same extent as farther seawards, and have also deepened and widened them, especially the transverse valleys. The continental shelf has comparatively recently been elevated, at least 300 m. higher than now, when the level of the barriers of the great submarine fjords was developed. There has probably been several pauses in these late elevations and submergences. How much the continental shelf has been elevated during previous oscillations of the shore-line cannot be determined, but the apparent irregular furrows on the continental slope off Romsdalen and Helgeland may indicate that during comparatively short periods it has been elevated as much as 800 m. (see p. 46) at least. If the deep ravines off Andøen (Andenes-jufta) and Senjen (see above p. 40) are eroded valleys, as might seem possible, it has been elevated still more.

The greater part of the Norwegian continental shelf has been formed before the coast platform, probably in pre-glacial times, but it has been greatly covered by glacial drift during the glacial periods. Its exact age cannot be determined, but as it seems to continue un-interupted outside the jurassic

region on Andø, it is probably Post-Jurassic, and even younger than the faults by which the jurassic layers of Andø were rescued from obliteration. To judge from the similarity between the continental shelves of Norway, the Færoes, and Iceland, it seems probable that the shelf is, at least to a great extent, *Post-Miocene, i. e. Pliocene* and *Pleistocene.*

THE ORIGIN OF THE CONTINENTAL SHELVES OF THE ATLANTIC AND THE NORTH POLAR SEA.

The differences in the width and depth of the continental shelves may perhaps sometimes be explained by local differences in the coastal sedimentation, in the wave-action, or in the geological structure of the coasts, by differences in coral growth, or also by unknown movements and depressions of the oceanic bed, and in other ways: but it is evident that no explanation can cover all cases; there are local causes, and each case has to be considered on its own merits and separately investigated, just as I have attempted above, in the case of the Norwegian continental shelf. The geological and morphological structure of the present coasts must be carefully studied, and likewise the deposition of waste on the sea-bottom, the topography of the drowned fjords and valleys, the subaerial erosion and the wave-action on the coasts, etc. It would not be possible to do all this in the present memoir, and in addition to what has already been said about the origin of the Norwegian continental shelf, I shall therefore only more briefly discuss the probable origin of a few other parts of the continental shelves of the northern seas.

Iceland and the Fœroes.

The continental shelf of Iceland (Pls. XXIV—XXVII) is obviously to a very great extent cut in rocks *in situ*: it forms a deep horizontal incision in the land, on all sides of the island, the mountains of which generally ascend abruptly from the coast (Sections 46—59). The coasts are also generally very steep and have a prominent cliff formation, which indicates that they have been much cut back by marine denudation; this is further proved by the islands and isolated 'stacks' with nearly vertical sides, often situated far outside

the coast, *e. g.* Eldey off Reykjanes, the Vestmanna Islands, and many others. The fact that the steep cliffs descend abruptly to the level of the inner part of the continental shelf, proves that the latter has been greatly carved by marine denudation. The recent excellent Danish charts of the east coast (see above p. 79) record frequently indeed "Hard Bottom" and "Stone" on the continental shelf, even at great distances from land (see Pl. XXVII, Sections 57—59, *Fj.* and *St.*). Commodore G. HOLM has been kind enough to explain to me that the designation "Stone" has been used wherever distinct impressions of rock on the tallow of the lead were obtained; it may consequently indicate either big stones or rock *in situ.* The designation "Hard Bottom" has been used where no bottom sample was brought up by the lead, and where the impression on the tallow of the lead gave no trustworthy indication of the nature of the bottom; it may consequently indicate either rock *in situ*, or big stones, or hard clay, or *Laminariæ*[1]. Where, however, the great majority of the soundings have given "Stone" or "Hard Bottom" the probability is, according to my view, that the bottom is to a great extent composed of rock *in situ.* Let us as examples consider the submarine ridge between Bakka-Floi Deep and Hjerads-Floi Deep (Pl. XXVII, Section 57) or the ridge between the latter deep and Seydis-Fjord Deep (Section 58). On these ridges, from the coast to the edge of the continental shelf — about 70—100 kilometres out to sea —, the soundings gave with very few exceptions "Hard Bottom" or "Stone". It is hardly possible that the rapid movements of the water (wave-movements and currents), which must exist over these high protuberant ridges, at depths of between 70 and 160 m., ever allowed clay deposits to settle there, and if they were already present they would be washed away; also there is the fact that with one or two exceptions clay has been found nowhere on these ridges. *Laminariæ* do not as a rule occur on the sea-bottom very far from the Icelandic coast, and will hardly be found at depths of as much as 100 m. on these ridges; and besides, where they exist there must be rock or stones to which they can become attached. The probability is therefore that on the above ridges "Hard Bottom" indicates as a rule rock or big stones; but as it seems highly improbable that the bottom over such

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[1] See also R. HAMMER in *Fiskeri-Beretning for 1898—99* by C. F. DRECHSEL, p. 173, and R. HÖRRING *ibid. 1900—1901*, pp. 186 *et seq.*

wide areas should be so densely covered with big stones that the lead would almost always hit them and nothing else, we are obliged to assume that these ridges are, at least to a great extent, composed of rock *in situ*. As, however, the ridges are simply parts of the continental shelf, we are thus also led to the conclusion that the continental shelf of Iceland, in general, is largely composed of solid rock *in situ*.

The Icelandic shelf cannot be a peneplain, for the whole island is too young. The shelf has probably been cut by the conjoint action of subaerial erosion and marine denudation. The greater part of the land cut away was obviously volcanic, and easily eroded. Volcanic rocks cover Iceland at least to a thickness of 3000 m., but we do not know at what depth their base lies, and therefore cannot say much about the nature of the rocks constituting the Icelandic continental shelf. The outer part of this latter may largely be built of river waste and glacial drift. Its surface now, is largely covered by coarse materials — sand, gravel, and stones, which is probably glacial drift. As I consider it impossible that a plain of marine denudation which has a width of more than 100 kilometres, and an extremely gentle slope, or is even nearly horizontal (see Section 57), could have been formed along an undissected coast (see above pp. 105 and 133), I think we are obliged to assume that the submarine fjords of the shelf have to a great extent existed before the shelf was formed[1]. The Icelandic continental shelf cannot have been cut by the conjoint action of subaerial erosion and marine denudation at present sea-level, for even though the shelf be composed of relatively weak basaltic and other volcanic rocks, the wave-action cannot have been capable of cutting a plain 100 kilometres broad to a depth of 100 m. and more, below the water

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[1] Dr. THORODDSEN objects (*Geografisk Tidsskrift*, vol. XVI, p. 74) that in this case, the submarine fjords must have been filled up by the waste of the marine denudation. It is, however, not proved that this may not have been the case to a very considerable extent. The present submarine fjords or valleys of the shelf form generally very shallow incisions of less than 80 or 100 m. below the highest ridges of the shelf (generally only between 20 and 60 m. below its general floor), and it does not seem possible that on this open coast, the open fjords could have been filled up by waste much higher than say 80 or 100 m. below the sea-level existing at the time, as the movements of the water were probably too rapid to allow the waste to settle. And besides, there is also the possibility that the submarine fjords may have been re-opened by the moving ice-sheets of the glacial epochs, or by atmospheric erosion during periods of elevation.

surface. We see therefore that if we assume that the shelf is cut in this manner we are also obliged to assume that it was formed at a lower sea-level, and this again forces one to the assumption of oscillations of the shore-line. In this case there is, however, no conclusive evidence that the Icelandic continental shelf has been elevated into dry land after its formation, as the bathymetrical features of the submarine fjords may be explained without such an assumption (see p. 169, footnote 1). The depths of between 400 and 500 m. of the great submarine fjords (above pp. 80—82, 83—84) seem to indicate a base-level of erosion during some previous period, but it is not absolutely certain that this was after the formation of the shelf[1], although it seems very probable.

Origin of the fjords of Iceland. It was mentioned above, on p. 79, that the topographical features of the Icelandic fjords and submarine fjords or valleys, differ much from those of the typical fjords of Norway and Greenland: the depths of the Icelandic fjords never even approach those of their submarine mouths on the edge of the shelf. The type of these fjords much resembles, that of the great fjords of Finmarken, the Porsanger, Laxe, and Tana Fjords (Pl. XI)[2], which are cut in the sedimentary rocks of the Gaisa system, while the typical Norwegian fjords are largely cut in Archæan rocks. The above Finmarken fjords are not much deeper than those of Iceland, and have no very deep hollows, it is also worthy of note that the type of the Finmarken coast, with no 'skjærgaard' and no dry coast platform except in the fjords, is very like that of Iceland. It seems probable that these similarities in the peculiar features of the coast and the fjords, are due to the geological structure of the lands. In Finmarken there was probably an extensive plateau consisting of nearly horizontal layers of sedimentary rocks, which has been sculptured by erosion, and in Iceland the plateaus built up by nearly horizontal layers of basalt may have offered somewhat similar conditions to the operation of eroding agencies. As early as 1867 PAIJKUL recognized that the fjords of Iceland had been sculptured by glacial erosion, and AMUND HELLAND has pointed out that their bathymetrical features are those of glacial fjords[3]; but to what extent these fjords have been excavated by the glaciers is difficult to determine. In Bardastrand there are, as THORODDSEN has pointed out (see above p. 159), fjords forming true rock basins, which have probably been carved out by glaciers, but they are only 170 m. deep. If we assume that the fjords have been cut chiefly by glacial erosion, it seems possible that the reason why they are so shallow in Iceland, is that the glaciers there were never so big as in Norway and Greenland; but why are the Finmarken fjords also so shallow? is it perhaps because this type of fjord is relatively broad, and widens out seawards? The glaciers were possibly rather allowed to abrade *horizontally*, and to expand, than jammed and forced to excavate *vertically* to the same extent as in the narrow channels of the Archæan regions. It seems nevertheless strange, that the Icelandic fjords are often so much shallower than their submarine prolongations on the continental shelf. Have perhaps the inner parts of the fjords in Iceland recently been filled up more than in Norway and Greenland? or did the Icelandic glaciers possibly reach the edge of the

[1] If the fjords were filled up by waste during the formation of the shelf, they may have been re-opened by glaciers reaching down to this depth below sea-level.

[2] Cf. OTTO NORDENSKIÖLD, *Bull. Geol. Inst. Upsala*, No. 8, vol. VI, Part II, 1899, p. 193.

[3] AMUND HELLAND, 'Færøernes Geologi' 1881, p. 25; and also, 'Om Islands Geologi', 1882, p. 16.

continental shelf during the greater part of the glacial periods? These are difficult questions to answer, especially as we find similar features in the Finmarken fjords. It seems at least improbable that the glaciers could have excavated the long submarine fjords across the broad and flat continental shelves of Iceland as well as of Finmarken, where the glaciers would evidently tend to join and form a more uniform ice-sheet.

According to my view, it is probable that the principal features of the surface relief of Iceland and its continental shelf, had been sculptured by subaerial erosion in pre-glacial times; these pre-glacial topographical features have afterwards been much modified by glacial erosion, the glaciers have excavated several fjords to form true rock basins, but they have not been able to deepen any of them to great depths[1].

If it be supposed that the continental shelf of Iceland is chiefly built up by loose materials, one is obliged to conclude that after formation it was elevated into dry land, at least 400 or 500 m. higher than it is at present, otherwise its submarine fjords could not have been eroded: these long channels, being continuations of the fjords and valleys of the coast, could not possibly have been cut by submarine glacial erosion across a perfectly flat and nearly homogenous sea-bottom, where the glaciers would certainly tend to form an ice-sheet of fairly uniform thickness.

We thus see that whatever theory we accept, the present Icelandic continental shelf is certain evidence that the shore-line has now a position which is different from what it was during long geological periods some time ago;

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[1] If it be assumed that the fjords and submarine fjords have, in general, been worn down by atmospheric erosion towards a base-level, it might seem natural that the fjords of the much younger Iceland should be shollower than those of the ancient lands of Norway and Greenland; for during the relatively short time in which the Icelandic fjords were being formed, the oscillations of the shore-line (or the base-level) may not have been so great as during the long periods of formation of the great fjords of Norway and Greenland. This consideration would speak in favour of the view that the great depths of the fjords are not chiefly due to glacial erosion; it ought, however, to be remembered that the relatively shallow Finmarken fjords are carved in rocks of the Gaisa system, which is generally believed to belong to the Triassic, Permian, and Carboniferous formations; they are at least much older than the rocks of Iceland, although on the other hand the Finmarken coast may be considerably younger than the Norwegian coast farther south. It can hardly be denied that the general aspect of the Icelandic fjords and valleys gives one the general impression of youth compared with that given by the Norwegian and Greenland fjords and valleys, and this might seem difficult to explain if the surface sculpturing of the lands were chiefly due to glacial erosion, for the latter has hardly obtained for a shorter time in Iceland than in Norway. The above-mentioned difference of aspect may, however, to some extent be explained as due to the different geological structure.

it indicates also with great probability that there have been several vertical oscillations of the shore-line.

The Age of the Icelandic Continental Shelf. Dr. THORODDSEN pointed out (*l. c.* p. 73) that the continental shelf of Iceland must have been formed after the extensive basaltic plateau of the island — built up of horizontal layers — was disturbed by great tectonic movements towards the end of the Miocene period, and it seems therefore probable that at least the greater part of the shelf is *Post-Miocene.* THORODDSEN assumes also that the shelf must be older than "Red Crag" and that it was consequently formed in the interval between the Miocene and the "Red Crag"; for considerable marine sediments from the latter period occur in the *Skjálfandi Bay* at *Tjörnes,* on the north coast of Iceland, and these sediments could not have been deposited at this place, if a high plateau-land, extending 100 kilometres into the sea, outside had been abraded after this period. This argument is, according to my view, of a somewhat doubtful character; as is mentioned above, I consider it necessary for the formation of the continental shelf, if it be cut by marine denudation, that the fjords existed before the shelf, and if so I see no objection why the sediments at *Tjörnes* may not have been deposited in such a fjord. It seems to me to be highly improbable that, if the shelf was actually cut by marine denudation in the Pliocene period, its formation should not have been continued during the Pleistocene and later periods: the traces of the marine denudation during the latter long periods must be conspicuous and must be found somewhere or other, and I know no other place to seek for them than on the continental shelf. I consider it, therefore, probable that *the continental shelf of Iceland was chiefly formed in pre-glacial times during the Pliocene and the Pleistocene periods.*

The continental shelf of the Færoes seems to be a formation which is perfectly identical to that of Iceland, and its history is probably exactly the same. The occurrence of the great Færoe Bank, far out to sea to the south-west of the islands, with depths very similar to those of the main shelf, appears to be weigthy evidence of the greater part of the shelf having been cut by marine denudation in rocks *in situ,* for this isolated bank situated so far from any land cannot possibly have been built up by waste, it is obviously an ancient island which has been entirely abraded to the level of the shelf.

The Fœroe-Iceland Submarine Ridge.

It seems highly probable that the Færoes and Iceland were once connected by a basaltic plateau emerging above sea-level. Although the plateau between the islands may have been depressed by dislocations and tectonic movements, its present relatively level submarine surface — which seems to mark an ancient sea-level — (see Pl. XXIV, and Pl. XXII, Sect. 46) cannot have been formed in this way. Its great distance from any land makes it also impossible that it has been much levelled by deposition of terrigenous waste of any kind[1]. We are thus, according to my view, obliged to assume that the ancient plateau or ridge has been abraded towards a mean base-level of erosion during some previous period when the shore-line, perhaps with several oscillations, stood on the average about 500 m. lower than now. The basalts and possibly other volcanic rocks, building up the upper part of the ancient plateau, were easily cut back by the conjoint action of subaerial erosion and marine denudation. If the Wywille Thomson Ridge, the Iceland-Greenland ridge, and perhaps also the ridge between Greenland and Baffin Land, are built up by solid rocks[2], we are obliged to assume that they have been abraded towards a mean base-level of erosion just as we have seen above, and during the same period. The great similarity of the depths of their surface (see above) can hardly be explained merely as an accidental coincidence. We thus see that the surfaces of these long ridges probably indicate an ancient mean base-level of erosion, which in a striking manner coincides with the level of the mouths of the great submarine fjords of Norway, Iceland, Greenland, and Canada.

It seems difficult to determine when the denudation of these submarine ridges took place, whether before or after or simultaneously with the formation of the continental shelf. As the basalts building up the plateau between Iceland and the Færoes, were probably of the same age as those of the latter,

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[1] "Stone" is recorded from several places on the ridge, especially on its more protuberant parts (see Pl. XXII, Sect. 46); it seems probable that the lead has at least at some of these places struck rock *in situ*.

[2] These ridges cannot possibly have been built up by loose materials. Even though icebergs and drifting floe-ice may carry much terrigenous matter during long periods, the width of these ridges and their height above the floor of the deep Ocean on each side, are too great for a slow mode of formation such as this to account for the facts.

it seems probable that the denudation of the ridges is at least *Post-Miocene*; I consider it probable that it occurred simultaneously with the formation of the continental shelf; the ridges were the whole time abraded towards the same levels, as the shelf, but as they were exposed to a very effective conjoint action of subaerial erosion and marine denudation on two sides, and were moreover possibly composed of weak rocks, the greater part of them was easily worn down to the lowest position of the shoreline just as I assume was the case on some parts of the shelf off the Norwegian coast (see above pp. 150, 166). It seems probable that the relatively short periods during which the shore-line had these low positions, were the same as those during which the levels of the mouths of the great submarine fjords of Norway, Iceland, Greenland, and Canada, were developed.

The Origin of the Færoe-Shetland Channel.

I consider it probable that the remarkably level bottom of the Færoe-Shetland Channel must have been formed by erosion of some kind. If we would assume, for instance, that this long channel was formed by dislocations, we would have to explain how its bottom became nearly horizontal, for to say that this is merely accidental is no explanation. It might be assumed that this approximate horizontality was developed by deposition of sediments, but this must have occurred at a corresponding sea-level, and we would not thus avoid the difficulty of the great vertical oscillations. It is according to my view, hardly probable, that the long and deep channel is an ancient river-valley; for we will be at some difficulty to find the drainage area necessary to form the great river which eroded this enormous valley, and simultaneously the river that eroded the valley on the south side of the Wyville Thomson Ridge. It seems to me, to be more probable that we have here an ancient channel between the Norwegian Sea and the Atlantic, which is older than the Wyville Thomson Ridge. At a sea-level, as much as 1200 m. lower than now, the Norwegian Sea and the North Polar Basin were transformed into lakes, if they had no outlets on other sides. But it is obvious that the enormous river running from these lakes into the Atlantic would comparatively soon erode its valley down to base-level, and thus a marine channel may easily have been formed. The shape of the Færoe-Shetland

Channel reminds also more of a marine channel than a river-valley; the remarkably uniform width both north and south of the Wyville Thomson Ridge (see Pl. XXIV) may most easily be explained in this way. By the formation of the Wyville Thomson Ridge during a more recent period when the sea-level was at least 700 m. higher, the channel was transformed into a deep cirque valley, with a nearly horizontal bottom. The depths may recently have been somewhat modified by deposition of sediments.

The West Coast of Europe.

BUCHANAN has in an ingenious manner tried to explain the formation of the continental shelf (which he calls the "coast flat") of western Europe and Africa, as being due to marine denudation at present sea-level, and he concludes that the great differences in the depths and width of the continental shelf are simply due to differences in the magnitude and effect of the wave-action at different places. He points out that at the entrance to the English Channel and in the Bay of Biscay, there are especially favourable conditions for the formation of a continental shelf; for "in no part of the world are the storms more frequent, more violent, and of greater duration than in this part of the North Atlantic", whilst in the Gulf of Guinea, where the shelf is so very narrow, there is practically no wind. He considers it also probable that the remarkable submarine channels of the Congo, the Fosse de Cap Breton, etc., have been formed at present sea-level[1]. BUCHANAN has not, however, proved that the wave-action may actually erode at depths of 160 or 180 m. (90—100 fathoms) — off the English and French coasts for instance — and if it does now erode at these depths it seems difficult to explain how the surface of the continental slope may then be covered by modern deposits; nor has he, I think, succeeded in giving a satisfactory explanation of how the submarine valleys or channels of the continental shelves may have been formed at present sea-level. It may farther be objected that BUCHANAN has not considered the varying powers of resistance possessed by the rocks building up the coasts, and that he has not taken into consideration that a great coastal deposition of waste must have occurred during the long

[1] J. Y. BUCHANAN, *Scott. Geogr. Mag.*, vol. III, 1887, p. 225.

period when these shelves were being cut back by the wave-action. The fact that there are numerous banks and shoals off the English Channel, lying at depths of about 100 m. or less near the edge of the shelf (see above p. 93) is not mentioned by BUCHANAN. If we agree with him that the continental shelves have been cut back chiefly by wave-action, they must according to my view, have been formed on dissected coasts and chiefly near sea-level, where the wave-action ist most effective by far. During previous oscillations of sea-level, the dissected coasts have, however, been worn down towards or below the lowest positions of the shore-line, where the wave-action was most violent or where the rocks of the coasts possessed the least power of resistance.

I shall not here go into detail how the continental shelf of the west coast of Europe may have been formed — whether chiefly by erosion or chiefly by waste — but shall confine myself to pointing out a few facts.

With the exception of the relatively shallow hollows and barriers of the Scottish and English submarine fjords, the bathymetrical features of the west European continental shelf north and south of the boundary of the glacial covering of the Great Ice Age, are not strikingly different, and this fact seems to prove that the topography of the continental shelf in these regions has not been much altered by glacial erosion or by glacial drift: the shelf off France and the English Channel does not differ more from that west of Ireland and Scotland, than can be most simply explained by the geological structure of the coasts. It might be more difficult to explain the great difference in width between the continental shelf off the French coast and that of the northern and western coast of Spain and Portugal (see next section).

Against those who maintain that the continental shelf of western Europe is simply formed by coastal deposition of waste, it might be argued that there is much evidence to show that great parts of this continental shelf must actually have been formed by erosion, — as I believe, by the conjoint action of subaerial erosion and marine denudation. The shelf west and north of Scotland carrying the many rocks and islands far out at sea — St. Kilda, Flannan Islands, Sulisker, North Rona, Nun Rock, etc. (see Pl. XXIII, and above p. 93) — cannot *e. g.* be heaps of waste, but the underlying ground must be rock cut back by erosion. It seems probable, that the Archæan gneiss region of the Hebrides and the NW-coast of Scotland extends in this direction;

and just as we have seen above (p. 148) is the case along the Norwegian coast, the Archæan part of the Scotch shelf rises to very similar, comparatively high levels and forms banks and shoals. I do not believe that the many small banks (at about 100 m. below sea-level) south of Ireland and off the English Channel (see above p. 93) are merely accidental heaps of waste, for I do not see how they could have been formed so far from *any* land, I believe they are ancient islands, composed of relatively hard rocks, which have been cut down below sea-level, and are situated on a rocky platform, traversed by numerous valleys now filled up by waste. It is probable that we here have a submarine Archæan region; north-western France is composed of Archæan and Palæozoic rocks, south-western England is also composed of very old rocks, and the rocks rising above sea-level near Eddystone are gneiss. The rocks of the English and French coast strike in a westerly or south-westerly direction (cf. E. SUESS, 'Antlitz der Erde', vol. II, p. 107; and T. G. BONNEY, *Quart. Journ. Geol. Soc.*, vol. XL, 1884, p. 24), like the rocks of south-western Ireland; and the shapes of the submarine banks are often elongated in the same direction. I may moreover mention that the Porcupine Bank and the Rockall Bank cannot be accumulations of waste, for there is no land anywhere near, from which the waste may have been carried (except by icebergs), they are evidently rocky plateaus which have been worn down and levelled just as in the case of the continental shelf[1].

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[1] It is worthy of note in this connection that many oceanic banks far from land, have depths which coincide in a striking manner with those of the continental shelves, I may instance the banks off north-western Africa and Spain (recently described by Dr. GERHARD SCHOTT in *Wissensch. Ergebnisse der Deutsche Tiefsee-Expedition, Valdivia*, vol. I, 1902, p. 101), the Josephine Bank (150 m. deep or perhaps higher), the Gettysburg Bank (55 m. deep), Coral Patch, Seine Bank (146 m. deep), Dacia Bank (91 m. deep), Concepcion Bank (179 m. deep), Born Felix Schoal (119 m. deep), Doric Bank (102 m. deep). Dr. SCHOTT does not believe that these banks are remains of older abraded islands (see *l. c.* p. 104), but assumes that they are submarine volcanos. It seems to me to be a strange coincidence that all these volcanos, and probably many more, should have happened to rise to such very similar heights below present sea-level, and with the sharply defined edges of their flat platforms lying at nearly uniform depths of almost 200 m. (196 m., 198 m., 177 m., etc.). I consider it most probable that they are volcanic islands which have been worn down, to their present level by marine denudation; Dr. SCHOTT's very instructive transverse sections of the banks (*l. c.* Pl. VI) strongly support this view, their profiles are not those of coral atolls, there are no indications of hollows in the centre of the banks; but if the upper configuration of the banks be not due to coral growth, their flat tops and sharply defined edges at nearly uniform depths are, I think, most simply explained by marine denudation, and this seems still more probable if it be considered how the depths and forms of the

It seems, on the whole, probable that the width of the continental shelf is to some extent dependent on the geological structure and height of the coasts, as might be expected, if they are formed more or less by subaerial erosion and marine denudation. I may mention as instance that the continental shelf is comparatively narrow and high off the Archæan regions of Norway, Scotland, the west coast and the south-east coast of Greenland. It seems to be broader off the north-east coast of Greenland, where there are tertiary basalts and other relatively young rocks. The North Sea and the Barents Sea are possibly regions where the greater part of the now eroded rocks have possessed no great power of resistance. The North Sea on the British, German, and Danish sides, is surrounded by low coasts largely composed of soft rocks. The coasts of the Barents-Murman Sea have evidently also to a great extent been composed of rocks which were rather easily eroded. On the Finmarken coast are the rocks of the Raipas and Gaisa systems which formerly may have had a wide extension eastwards along the present Murman coast, where they still occur on the Rybachy Peninsula, and Kildin, as well as on the Kanin Peninsula. On Novaya Zemlya there is much soft sedimentary rock. Along the coasts of Yugor Strait I found soft Silurian clay slates, on Vaigach there are soft Devonian rocks. The Frantz Josef Archipelago is composed of basalts resting on very soft Jurassic clay, which is easily washed away by marine denudation. King Charles Land is built up in a similar way. On the eastern side of the Spitsbergen Archipelago there is much basaltic and other weak rock. Bear Island and Hope Island are also composed of relatively weak rocks. It may thus be possible that this was formerly an exten-

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upper platform of these banks coincide with those of the continental shelves. It might be possible that, at least the shallower banks have been worn down by wave-action at present sea-level; Dr. SCHOTT even mentions that heavy breakers have been observed on the Gettysburg Bank, and he believes he has noticed that the waves were more choppy over the Seine Bank than over the deep ocean at the sides. But the sharply defined edges of the banks are so deep, near 200 m., that I consider it more probable that the banks have been abraded by marine denudation at an earlier, lower sea-level, just as have large parts of the Norwegian continental shelf. The fact that sharply defined edges of these banks seem to lie at a depth of nearly 200 m. while the edge of the continental shelf of the African continent, *e. g.* in the Gulf of Guinea (cf. BUCHANAN, *l. c.*), seems to be at about 90 m. may be due to the circumstance that the banks are composed of comparatively weak volcanic rocks, and further, to the fact that the wave-action in the open ocean, is heavier than on the continental coast.

sive low region largely composed of weak rocks, on which subaerial erosion and marine denudation have had a great effect, and that the wide continental shelf between the Norwegian-Russian coast and Spitsbergen-Frantz Josef Land, has been formed in this way; its underlying ground is consequently to a great extent rock *in situ*, and not modern loose materials. The drainage-area of the rivers now running into this sea, seems also much too small to explain a possible silting up by waste of such an enormous region.

We do not know what the conditions may have been to the north of the present Siberian coast, or whether the apparent great width of the continental shelf on this side of the North Polar Basin may be explained by the former occurrence of an extensive lowland composed of weak rocks, which were easily eroded to base-level, or whether the Siberian shelf is rather built up largely of waste carried north from the extensive drainage-area of the Siberian rivers. Both circumstances may probably have been of importance, as we see that the present coast is partly composed of modern loose materials (*e. g.* Yalmal, the coast of Toll Bay and mouth of Taimur River, Semenov and Vasilyev Islands, Liakov Islands, etc.), and partly of rocks from different periods, which were, however, at some places obviously cut back by marine denudation to form a coast platform (se above pp. 20, 102). The coast of the Western Taimur Peninsula was composed of crystalline schists (mica-schists) and granites at the places where we were ashore[1] and this seems to explain the actual existence of a 'skjærgaard', with skerries and islands, as well as numerous fjords and sounds along this coast. On the Chelyuskin Peninsula there is evidently also to some extent fairly hard rock, on the north-eastern corner we found a hard quartzite, but near Vega's harbour at Cape Chelyuskin NORDENSKIÖLD found clay-mica-schists, and off the west coast and north coast of this peninsula we also observed some few islands. On the New Siberian Islands TOLL and BUNGE have found Silurian and soft Tertiary rocks. On Bennett Land, according to DE LONG's diary, the Jeanette people seem to have found basalt ("lava") and young formations with lignite. On the Siberian coast young formation do not on the whole, seem to be uncommon. It is thus possible that we have here a region which has been

[1] A. E. NORDENSKIÖLD found gneiss, mica-schists, and dioritic schists, see A. E. TÖRNEBOHM, *Vega-Exped. Vet. Iakttagelser*, vol. IV, 1887, pp. 116–119.

relatively easily eroded towards a peneplain, and this lowland may also have been much cut back by marine denudation, for although the wave action is relatively insignificant in the present ice-covered sea, it may have been vigorous in periods when the North Polar Basin was more or less open. At the same time there has probably also been much deposition of waste in this sea, especially during periods when the climate of Siberia was moister than it is now.

Relation between the width of the Continental Shelves and the prevailing winds.

If *marine denudation* has played a prominent part in the formation of the continental shelves, we must expect the latter to be well developed on coasts where favourable conditions for marine denudation, have prevailed. This is evidently the case to a very great extent.

The effect af marine denudation will depend on: 1) the wave-action on the coast, 2) the oscillations of sea-level (chiefly by tides) increasing the area attacked by wave-action, 3) the power of resistance of the coastal rocks, 4) the topographical features of the coast.

The effect of the wave-action is evidently dependent on the strength of the winds, their average direction (wether they are directed landwards or seawards), and the depth and extension of the ocean bounding the coast. It is, however, a very difficult problem to find the exact relation between the erosive effect of the wave-action and the wind. For on the one hand the great oceanic waves produced by strong winds travel great distances beyond the region over which the winds blow — *e. g.* the surge on the coast of Guinea Bay, and St. Helena, is due to swell originating from winds in higher latitudes — and on the other hand the erosive effect of wave-action is evidently proportionate to a very high power of the velocity of the wind producing the waves. The mechanical effect of the breakers upon the shore is measured by their kinetic energy, which increases as the third power of the hight of the waves[1]. During storms the latter, is according to G. SCHOTT, nearly equal to half the velocity of the wind expressed in metres per second; but during

[1] A. PENCK, Morphologie der Erdoberfl., vol. II, p. 465.

weaker wind the heights of the waves are much smaller. On the other hand the frequency of the waves is greater during weaker than during stronger winds, and this may check the effects of the above fact, although only partially; and we may assume that the kinetic energy of the breakers on the shore increases at least as the third power of the wind-velocity, provided that the wind is blowing in the same direction. But the erosive effect of wave-action does not only depend on the kinetic energy of the breakers against the shore, but also on the transporting capacity of the water on the sea-bottom near the coast, maintained in motion by the waves. If we mean by *transporting capacity*, the capacity moving water has to transport stones of different sizes on the bottom, it is proportional to the sixth power of the velocity of the current, and provided that the orbital velocity of the wave movement is proportional to the height of the wave, and that the latter is, in the case of storms, equal to half the wind-velocity, we find that the transporting capacity of the wave-action on the sea-bottom would increase as the sixth power of the wind-velocity, provided that the mass of water put in motion be sufficiently deep. This means that if a storm be increased to the double velocity, the correspondingly increased wave-motion on the sea-bottom near the coast, will be able to move pebbles or boulders sixty-four times the weight; with other words, a slight increase of the wind-velocity might have a very considerable effect on the size of the boulders moved on the sea-bottom.

If we assume that the destructive effect of the wave-action on the shore increases only as the third power of the height of the waves (or of the wind-velocity), we must conclude that in regions where storms are frequent the marine denudation must be considerably greater than on less storm-beaten coasts, even though the average height of the wawes or the average velocity of the wind during the year, may be greater in the latter than in the former case. If on a coast the average height of the waves during the year be 1 m., the erosive effect of the wave-action will be

$$E = t\ a\ 1^3$$

(where t is the time, and a is a constant) if the waves have had the same height during the whole time. But if the waves were 2 m. high during half the time, while the sea was calm during the rest of the time, we find

$$E = \tfrac{1}{2}\ t\ a\ 2^3 = t\ a\ 4.$$

We see that in the latter case the effect of the wave-action on the coast is four times greater than in the former case; and if the waves were 4 m. high during one quarter of the time, and there was a calm sea under the rest of the time, we find

$$E = \tfrac{1}{4}\, t\, a\, 4^3 = t\, a\, 16.$$

In this case the effect is sixteen times greater than in the first case, and if in the first case the average height of the waves had been double, the effect of the wave-action would only be half of what it was in the last case. It is here provided that the frequency of the greater waves is the same as that of the smaller ones, which is not, however, quite correct.

If we assume that the effect of the wave-action increases only as the second power of the wave-height, or as the second power of the wind-velocity, we see that in the second case above, the effect would be double that of the first case; and in the third case it would be four times that of the first case in other words it would be the same as if the heights of the waves had been doubled in the first case.

It will thus be seen that if we only know the average height of the waves or the average wind-velocity on a coast, it is impossible to calculate the probable effect of the wave-action, and even where the variations of the wave-height during the year is known, this calculation will be a very complicated affair. But the calculation of the erosive effect of the wave-action on the coast is still more complicated by the fact that the erosion is not only dependent on the height of the waves, but also, to a very great extent, on the shape of the coast and on the depth of the sea outside; in one case the greater part of the kinetic energy of the waves may be expended in destroying the cliffs of the shore, while in another case it may be used to transport the gravel on the flat sea-bottom or to build up a beach. The former case may occur during the first period of the formation of a coast platform, whereas the marine denudation is much reduced when the submarine platform acquires a certain breadth. It would therefore by no means be correct to say that the width of the continental shelves formed chiefly by marine denudation, or the quantity of material cut away by marine denudation, must be proportional to a certain power of the wave-height, and still less to a certain power of the mean wind-velocity. It would in fact be an extremely difficult task to procure

the data necessary for a satisfactory comparison of the probable effects of marine denudation at different places.

We may, however, expect that, on the open coasts of a deep and wide ocean, the continental shelf has been most developed on the most storm-beaten coasts where the prevailing storms are directed landwards, provided that the rocks or the shape of the coasts do not offer too great resistance. Let us, as an example, look at the coasts of the Atlantic, and let us suppose that the meteorological conditions during previous geological periods, have been somewhat similar to what they are to-day. We here find a tolerably good confirmation of the above conclusions.

On the African coast which is on the whole comparatively high, and largely composed of ancient hard rocks, the winds are not strong and storms very rare, the prevailing winds are on the whole, mainly directed along or from the coast. There is also a very narrow and relatively high continental shelf. It is narrowest in the tropical region between 5° N. Lat. and 15° S. Lat., where the winds are on the whole very weak, as pointed out by BUCHANAN. Along the SW-coast of Africa, where storms are more frequent, the continental shelf is broader. Along the NW-coast, between Sierra Leone and the Canary Islands, where the land is comparatively low, the continental shelf is also broader.

On the east coast of South America, where the winds are on the whole stronger than on the African coast and are prevailingly directed towards the coast, except in the southern part, and where the coast is also to some extent low, the continental shelf is broader. An exception is perhaps the Brazilian coast between 5° and 15° S. Lat., but this coast is comparatively high and mostly composed of hard Archæan rocks. It seems, however, a strange fact that the SE-coast of South America has such an exceptionally broad continental shelf, for the prevailing winds blow from the coast eastward; but the coast, composed of weak rocks, is not very high, and it is a very stormy region; and besides it is well known that the highest waves known are generally observed in the sea to the south of Patagonia. It might also seem strange that the northeastern coast of South America has a very broad continental shelf, although the winds in this region are not strong, but the coast is low and there has probably been much coastal sedimentation of waste from the Amazons, the Orinocco and other rivers.

The northern Atlantic, north of the Spanish Peninsula on the European side and north of Florida on the American side is a very stormy region, and there are here relatively broad continental shelves on both sides of the Ocean. On the European side the storms are largely directed towards the coasts and come in from the wide and deep ocean. Running along the European coast from the head of the Bay of Biscay to the north, there is, as mentioned above, a comparatively broad and rather deep continental shelf, which extends as far north as Spitsbergen. This continental shelf is fairly broad even off the high Norwegian coast largely composed of hard Archæan rocks. The striking difference in the width of the continental shelf north and south of the Bay of Biscay was mentioned above, the explanation may be to some extent, that storms are more frequent north of the Spanish Peninsula than farther south.

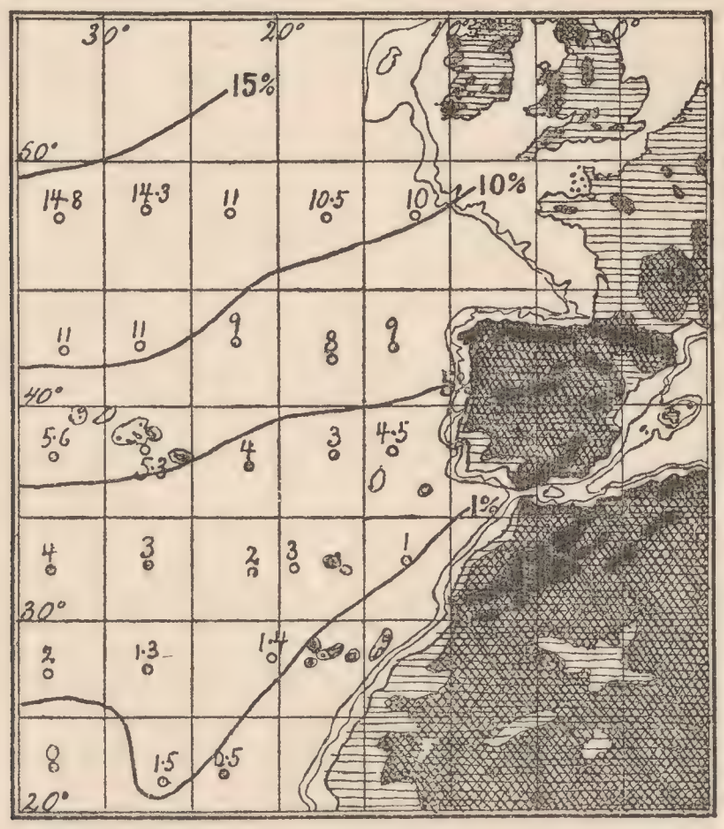

Fig. 6. *Frequency of storms.* The figures indicate percentage of all observations during the year, giving higher wind-velocity than 8 BEAUFORT scale (or 14 m. per second). *Isobaths* are drawn for 200 and 1000 m. *Light shading* indicates lowland from 0—200 m. above sea-level. *Dark shading* indicates heights of 200—1500 m. *Black* indicates heights above 1500 m.

Fig. 6 demonstrates roughly, the annual frequency in the sea off these coasts, of storms stronger than 8 of the Beaufort scale (= 14 m. pr. second)[1]. It is seen that while off the English Channel and in the Bay of Biscay, between 50° and 45° N. Lat., about 10 % of all observations during the year give storms of a higher velocity than 8 Beaufort scale, there are: about 9 % storms off the southern Bay of Biscay and the Galizian coast, between 45° and 40° N. Lat.; 4·5 % storms off the Spanish-Portugese coast, between 40° and 35° N. Lat.; and only 1 % storms off the African coast, between 35° and 20° N. Lat. It

[1] The map is compiled from 'Atlantischer Ozean', second edition, 1902, published by *Deutsche Seewarte*, Pl. 26—27.

has been shown above that a slight difference in the strength of the storms might produce a very great difference in the destructive effect of the wave-action on the shore; in order to decide whether the above differences in the frequency of the storms are sufficient to explain the striking difference in the width of the continental shelf north and south of the Bay of Biscay, it would therefore be necessary to carefully study at the several places the force of the wave-action during the several storms of the year. BUCHANAN explains the decreasing width and depth of the French continental shelf in the southern part of the Bay of Biscay (off Cape Ferret, *l. c.*, p. 227) by the circumstance that the storms "blow with their greatest violence while veering from SW through W to NW", and the southern part of the French coast "does not experience the full strength of the waves until the wind has passed from SW to W". If this explanation be correct, the narrowness of the continental shelf off the northern coast of Spain may be still better explained in the same way.

Considering that the French and English-Irish coasts are comparatively low, and largely composed of rocks which possess a small power of resistance, while the northern and north-western coasts of the Spanish Peninsula are very high, and, especially in Galizia, are composed of Archæan rocks which possess a high power of resistance, it might not seem impossible that the different frequency of storms may go far to explain the different width of the continental shelf. It is also possible that the ancient low Irish, English, and French coasts were originally more deeply dissected than the Spanish-Portugese coast before the continental shelf had been developed. On the other hand the possibility is perhaps not altogether excluded, that there have been more recent changes of level on the African and Spanish coasts than farther north; comparatively recent dislocations may, for instance, have occurred on the sea-bottom and reduced the width of the continental shelf.

Off the east coast of North America, north of Florida, the continental shelf is on the whole broader than on the European side of the North Atlantic, and although it is a very stormy region, often visited by violent storms, this might nevertheless seem astonishing, considering that the prevailing winds blow *off* the coasts; but we do not know what the winds may have been in earlier geological periods; and besides, the coasts are low, and the continental shelf seems at least to some extent, to be a continuation of the coastal plains of the coast. The prevalence of off shore winds may perhaps help to explain

the fact that the general floor and the edge of the east American continental shelf, stand so much nearer present sea-level than do those of the European continental shelf (cf. above p. 96).

On the whole it may be said, that, at least in the Atlantic and the Indian Sea, there is in higher latitudes a certain tendency towards broader continental shelves; and this may perhaps to some extent be explained by the fact that marine denudation is, in general, greater in higher than in lower latitudes, for storms are there more frequent, the climatic conditions are more severe, and the coasts are more dissected.

THE AGE OF THE CONTINENTAL SHELVES.

It has been mentioned above (p. 173) that the continental shelves of Iceland and the Færoes are probably of Plio-cene and Pleistocene age, and as these lands have evidently been built up in Tertiary times, their continental shelves cannot possibly be older. I believe that the continental shelves of other regions are to a great extent of similar ages; although their formation may naturally have commenced long before the periods when the basaltic plateaus of Iceland and the Færoes were built up; the continental shelves in other regions are also often much wider than those of Iceland and the Færoes. In Scotland and on the Scotch islands there are extensive basaltic plateaus probably of much the same age, they are at least Tertiary, but the continental shelf has evidently, at least to a great extent, been formed after the eruption of these basalts, as its plane cuts the basaltic regions as well as the Archæan regions, without exhibiting any striking difference. Prof. E. HULL is also of the opinion that the submerged physical features of the west coast of Europe, received their definite outline in Mio-Pliocene and Post-Pliocene times[1].

Prof. J. W. SPENCER has been kind enough to let me see the proofs of a paper on submarine valleys which he is going to publish shortly[2]. He

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[1] E. HULL, *Trans. Vict. Inst.*, 1899.

[2] J. W. SPENCER, 'Submarine Valleys off the American coast and in the North Atlantic'. *Bull. Geol. Soc. America,* vol. XIV, 1903. In this paper which I saw after the preceding chapters had been printed, Prof. SPENCER draws attention to a great many of the submarine valleys off the coasts of Canada, Newfoundland, Greenland, Iceland, the Færoes, etc. which have also been described above in chapters VI—VIII. As he

draws attention to the fact that "off *Cape Hatteras*, dredgings bring up quantities of old Miocene water-worn shells mixed with modern species. Miocene beds occur in Maryland and New Jersey" and in "Martha's Vineyard, and have been recovered by dredgings from depths of 35 to 70 fathoms, off the Georges shoals, south of the Gulf of Maine". "The same have been found on the Banquerean, south-east of Cape Breton, adjacent to the Laurentian Channel. Again Tertiary fossils have been obtained from the great bank of Newfoundland (lat. 44° 30′ N., long. 50° 15′)". As the drowned plains of Maryland and New Jersey are covered by sands, while fine blue clay is found in the Hudson Channel, where it incises the continental shelf[1], Prof. SPENCER concludes that "the completion of the valleys of the submarine coastal plain has occurred since the old Miocene period". Prof. W. J. Mc GEE has shown that the great period of erosion was after the accumulation of the Lafayette formation, and these deposits, as SPENCER has seen, underlie the drift of New Jersey. "The Lafayette was accumulated after a long period of Tertiary erosion of this region, and is provisionally regarded as of late Pliocene age". Prof. SPENCER concludes therefore that, "the formation of the channels of the coastal plain, or their re-opening, was after the Lafayette period, or early Pleistocene epoch, when the fjords of Newfoundland and Nova Scotia were fashioned, but prior to the accumulation of the drift or the Columbia formation, both of which kinds of deposits rest on the post-Lafayette topographic surface". I suppose that Prof. SPENCER does not deny the possibitity that during the period of the accumulation of the drift there may have been elevations of the continental shelf sufficiently long to re-open to some extent the submarine channels; to judge from the features of the Norwegian continental shelf I believe that this has been the case (see above p. 162). SPENCER does not discuss the age of the continental shelf, he only says that from its continuity with the coastal plain, and the occurrence of similar formations on the

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has evidently not had very detailed charts at his disposal, his descriptions of some submarine valleys — *e. g.* north and south-east of Iceland, north of the Færoes, west of South Cape on Spitsbergen, east of the north-east coast of Greenland — are hardly quite correct. On the whole I think Prof. SPENCER rather tends to trace out his submarine valleys to much greater depths than is warranted by the charts.

[1] The most natural explanation of this fact seems to me to be, that while the clay was washed away from the bottom of the shallow sea, it was allowed to settle on the bottom of the deeper channel; it is, as we see, exactly the same feature as in all Norwegian submarine fjords (see above pp. 143—144).

outlying banks, one is led to conclude that the plains, whether now above or below sea-level, form one feature, and that the sands, more or less filling the valleys, are only such a feature as would be produced by the slight changes of level that have occurred since the mid-Pleistocene epoch". He also draws attentions to the important fact that *the banks of Newfoundland "show the same character of submarine plains as in the region south of the drift"*, and that they "are not so covered with drift as to prevent the recovery of Tertiary deposits and establish the common origin of these plains with those existing in New Jersey". It might perhaps be objected against SPENCER's arguments, that the Tertiary fossils on the submarine plains may have been transported by ice from land comparatively recently; but this is, at any rate, hardly possible off Cape Hatteras or in the region south of the glacial drift, for if so other drift was certain to be found along with the fossils. It is equally improbable that the fossils could have been transported such a great distance from the coasts to where they now occur by water movements along the bottom, *e. g.* on the Newfoundland Bank, or off Georges Shoal. The most natural explanation is, I think, that the Miocene deposits may partly have aided in building up and levelling the plain of the continental shelf, and that the latter may also have been partly cut in these deposits during post-Miocene times. As the plane of the continental shelf seems to cut, to some extent, the great features of erosion of the Lafayette period, it seems possible that it has also partly been formed after this period.

To judge from what has been said above of the age of the continental shelves of America, Iceland and the Færoes I consider it probable that the present continental shelves of the world have to a very great extent been developed during Pliocene and Pleistocene times.

IS IT POSSIBLE THAT THE PRESENT BATHYMETRICAL FEATURES OF THE DROWNED VALLEYS AND FJORDS CAN BE EXPLAINED, UNLESS WE ASSUME THAT THE CONTINENTAL SHELVES HAVE, AFTER FORMATION, BEEN DRY LAND?

This is an important question which ought to be discussed separately. On formerly glaciated coasts there is the difficulty that we do not know how far the ice-sheets extended into the sea, and, as was pointed out above (p. 163), the possibility cannot be excluded that the ancient drowned fjords and valleys which had been filled up by waste, have been more or less re-opened by the submarine erosion of the glaciers. Absolutely conclusive evidence of a recent elevation of the continental shelf are therefore difficult to find in such regions. It has been pointed out above that the features of the Norwegian submarine fjords seem to indicate a recent elevation of at least 300 m. and probably more, and the furrows of the continental slope at Storeggen and farther north may perhaps indicate still greater elevations (see above pp. 46, 54, 167). It might also seem difficult to explain the bathymetrical features of the drowned valleys of the Barents-Murman Sea and the Kara Sea (see above pp. 24, 26) unless we assume that the sea-bottom has been recently elevated into dry land. On the bottom of the North Sea there are hardly any traces of the channels of the Elbe, the Rhine and the English rivers which once traversed this region, but which has evidently been filled up, perhaps very largely by glacial drift, and it seems difficult to find conclusive evidence of a recent elevation.

In more southern regions beyond the boundaries of the ancient ice-sheets the drowned river-valleys have evidently been much silted up. On the south-west side of England the drowned river-valleys of the St. George Channel River, the English Channel River, etc. have been silted up to a very great extent. Although traces of them may be found near the coasts — *e. g.* the Hurd Deep, in the English Channel, and the shallow hollows of the St. George Channel — they seem to have been almost entirely obliterated on the continental shelf farther seawards, where the filling up by waste may have been greater[1]. Only

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[1] For instance, the fact that the ancient valley of the English Channel river has been more filled up farther from land than at the place where we now have the Hurd Deep, might possibly indicate that these features were developed at a time when the sea-bottom stood relatively higher (see above p. 161).

at the edge of the shelf and on the continental slope are there deep gullies which might indicate their mouths (see above p. 94). Off the west coast of France there seem to be similar conditions: the Loire has, according to Prof. HULL, a drowned channel traversing the continental shelf, but this channel is at any rate very shallow, while at the edge of the shelf there is a fairly deep embayment. Off the mouth of the Gironde there seems also to be an embayment in the edge of the shelf, but there is no distinct channel across the shelf itself. These features are not quite incompatible with the assumption that the shelf was formed after the drowned valleys; for even if the shelf were chiefly built up by waste, there may still be traces of the ancient valleys in the shallow sea near land, as well as near the edge of the shelf. The deposits will sooner build up the shelf to its proper height and to a greater width on the sides of the deep valleys, than over their bottom; and embayments in the edge of the shelf will thus arise. If the shelf was greatly cut by marine denudation, it is also possible that traces of the ancient drowned valleys may still exist, especially near the edge of the shelf, as it is hardly probable that these latter would be entirely filled up level with the rocky ridges at the sides, especially if the latter rise above the base-level of the disturbing influence of the wave-movements on the bottom sediments (see above p. 170, footnote). It is perhaps also worthy of mention, that the currents of the sea are much influenced by the surface relief of the sea-bottom; and where there are deep drowned valleys and fjords on the Norwegian continental shelf, the currents are much more rapid than in the shallower sea at the sides.

The bathymetrical features of the deep and well preserved *Fosse the Cape Breton*, at the head of the Gulf of Gascony, seem, however, to be perfectly incompatible with the assumption that the shelf was formed after the last submergence of the drowned valleys, if we assume that this remarkable ravine is an ancient river canyon, other than which I think there is no feasible explanation (see above p. 95). It is certainly a peculiar fact that just at this very place, there is a sudden change in the shape of the continental shelf, from the broad submarine plain off the low French coast to the north, to the narrow much indented ledge along the steeper Spanish coast on the south side of the bay, but this difference may perhaps be explained by differences in the wave-action as well as by differences in the geological and morphological structure of the coasts, etc. (see above p. 185). It is obviously impossible that the

continental shelf could have been built up by waste, after the last submergence of this canyon, for else it would have been filled up at least to some extent, especially near the coast, and if the continental shelf has been entirely cut by marine denudation, the canyon must also have been largely filled up by waste during the long period necessary for this erosion. The bathymetrical features of some of the deep submarine ravines off the coasts of Spain and Portugal (see HULL, *l. c.* 1899) may also be very difficult of explanation if the shelf was formed after the last submergence of these valleys.

Along the west coast of Africa several splendid drowned river valleys occur, I may especially mention the great Congo Submarine Canyon[1]; the Bottomless Pit[2] and the Cape Verde Channel[3], and on the east coast the submarine channel of the Rovuma River[3] are also worthy of note. The continental shelf of Africa is, on the whole, narrow and shallow, it nevertheless, seems impossible to assume that this shelf was formed after the last submergence of the drowned river valleys, *e. g.* that of Congo, for in that case the valleys must have been filled up, at least near the coast, even if we assume that the shelf was entirely cut by marine denudation; the water-movements could not possibly have prevented sediments being deposited near the coast on the bottom of the channels at depths of more than 1000 m., *e. g.* off the mouth of the Congo River. The bathymetrical features of these drowned valleys are such as might be expected if the valleys have been sculptured by erosion during a recent elevation.

We see that it is difficult to find absolutely conclusive evidence that the continental shelf of the Eurasian coasts between the Bering Sea and Africa has been elevated into dry land after formation; but the drowned valleys and fjords at many places make this highly probable and at some places — *e. g.* the Fosse de Cape Breton, the Congo Submarine Canyon, the Bottomless Pit — there seems to be no other feasible explanation to be found. Some drowned river valleys on the American side of the Atlantic seem perhaps to give still better evidence of such a recent elevation. Even if we admit that the long submerged channel of the *St. Lawrence River* might possibly, although not

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[1] E. STASSANO, 'La foce del Congo', *Atti Real. Accad. Lincei,* Anno CCLXXXIII, 1885–86 vol. II, 1st semestre. See also BUCHANAN, *Scott. Geogr. Mag.*, vol. III, 1887, p. 222.

[2] BUCHANAN, *l. c.*

[3] BENEST, 'Submarine Gullies, etc.', *Geogr. Journal,* 1899, p. 394.

probably, have been re-opened by submarine glacial erosion, it seems improbable that in this case the deep gullies on the continental slope at its mouth (see above p. 97), should not have been filled up by glacial drift. It seems also highly improbable that the drowned valleys of the *Newfoundland Bank* far from land (above p. 98) have been re-opened by submarine glacial erosion. The drowned valley of the *Hudson River* (above p. 98) cannot possibly have been re-opened by submarine glacial erosion, it is too long and narrow, and too deep. Its narrow and sharply defined channel, cut in the extremely level continental shelf, seems to prove that the latter has comparatively recently been elevated into dry land. Prof. J. W. SPENCER has described a great many drowned valleys along the coasts of the West Indies and the United States south of the drowned Hudson valley[1]. Although SPENCER's description of the drowned valleys may often be based on too few and scattered soundings, to be absolutely certain, there are evidently a good many submarine features in this region which cannot easily be otherwise explained, and which indicate vertical oscillations of great amplitude, of the shore-line, as Prof. SPENCER has pointed out in such an ingenious way. According to his investigations the drowned valleys of the continental shelf as well as the valleys of the coast, have been filled and re-opened several times according as the shelf was submerged or elevated into dry land. But, as at least some well defined drowned valleys, according to his descriptions, seem to traverse the level plain of the shelf almost from the present coast, we are obliged to assume that the present general floor of the continental shelf had already been extensively developed prior to its last emergence, and the shelf cannot have been covered by much deposit after the last submergence.

We thus see that at least at several places there is weighty evidence that the drowned river-valleys have been sculptured after the formation of the continental shelves, and that consequently the latter have been dry land after formation, and if this has been the case at some places, we are obliged to assume that this has also been a general occurrence at least in neighbouring regions; for considering that the continental shelves have retained practically the same level mutually, the oscillations of level cannot have been due to quite local tectonic movements.

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[1] J. W. SPENCER, 'Reconstruction of the Antillean Continent', *Bull. Geol. Soc. America*, vol. VI, p. 111.

SUMMARY.

The results of the preceeding discussion of the origin of the continental shelves may be thus summarized:

The continental shelves of the world have been formed partly by *coastal deposition of terrigenous waste*, and partly by the *conjoint action of sub-aerial erosion and marine denudation*. In seas where the temperature has been sufficiently high during modern or former geological periods, *coral growth* may also have been of more or less importance.

In regions where the *coastal sedimentation* has been rapid this mode of formation has been of chief importance; for the great amount of waste carried into the sea will there fill up and level the sea-bottom and protect the coasts against the attacks of wave-action, and the kinetic energy of the latter will to a great extent be expended in moving and grinding the latter. It was pointed out (pp. 146—147) that off coasts where much waste has been carried into the sea, the continental shelves are generally broad — *e. g.* of the mouths of the Amazon, La Plata, Orinocco, Mississippi, the Siberian rivers, the East China Sea, the northern coast of the Black Sea, etc. The narrow shelf off the mouth of the Kongo is a remarkable exception.

But on the other hand it is not at all certain that favourable conditions for coastal sedimentation have prevailed wherever comparatively broad continental shelves or banks occur: I may instance the shelf of the Færoes, the Rockall Bank, the Newfoundland Bank, the exceptionally broad shelf of the east coast of Patagonia, the broad shelf off the English Channel, etc. In many such cases we are obliged to assume that erosion has been of predominant importance in the formation. It was pointed out that great parts of the continental shelves of Norway (pp. 151, 166), the Færoes (p. 174), Iceland (p. 171), the British Isles (p. 178), have obviously been cut in solid rock at sea-levels lower than the present one: It can hardly be merely an accidental coincidence that these shelves have nevertheless levels which are nearly identical with those of other continental shelves; it seems more probable that even parts of the latter have likewise been cut by marine denudation and subaerial erosion, for there is no reason why the latter agencies have not also been simultaneously more or less active along the other coasts. The continental shelves, partly cut by erosion and partly built up by waste, may thus be considered

as features which, on a small scale, are illustrated by the raised shore-ledges, cut in solid rock, and the raised beaches and terraces built up by waste, forming continuous levels in the Norwegian fjords.

The conjoint action of subaerial erosion and marine denudation had the greatest effect during periods of oscillations of the shore-line. During periods of seaward movement of the shore-line, when the region of the continental shelf was emerged into dry land, the subaerial erosion would tend to wear the emerged land towards the base-level of erosion, and would dissect the coast; during the subsequent period of landward movement of the shore-line the thus dissected coast would be submerged and offer the most favourable conditions to marine denudation. By repetitions of this process broad continental shelves may have been formed; and in the history of most coasts there have probably been many oscillations of the shore-line.

During the oscillations of the shore-line the continental shelves were worn down to the lowest levels in those regions where the marine denudation was most effective, or where the coastal rocks possessed the least power of resistance.

The effect of marine denudation can never become great on smooth, undissected coasts, where the shore-line remains stationary. Dissected coasts will be cut back till they become smooth.

The continental shelves of the world have been subjected to changes of level simultaneously with, and after their formation; they have only to a very small extent been formed after the time, when the present shore-line was attained.

X. STABILITY AND OSCILLATIONS OF SHORE-LINE.

The comparatively broad and well developed continental shelves of the Earth, standing near present sea-level, and the absence of similar extensive structures at greater depths[1], prove that the general level of the hydrosphere must have remained near its present position during long recent geological periods. This is still better proved by the surface of the continents.

According to Sir JOHN MURRAY[2] about 8·09 % of the surface of the Earth stands between 0 and 200 m. above present sea-level, and about 5·3 % lies between 0 and 200 m. below sea-level[3]. If we consider the continental shelves, or the region of the Ocean shallower than 200 m., as belonging to the continents, the continental area covers about 33 % of the Earth's surface[4]. About 24·5 % of this continental area stands between 0 and 200 m. above sea-level, and about 16·1 % between 0 and 200 m. below sea-level; that is to say, *about 40·6 % of the continental area of the Earth stands between 200 m. below and above present sea-level.* If we assume the boundary of the lowlands to be at 500 m. above sea-level, we find that no less than about 63 % of the above continental area is lowland.

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[1] The *Blake Plateau*, off the east coast of the United States, and other suboceanic terraces are probably similar structures, but they have evidently not the same universal distribution along the continental coasts as the present continental shelves.

[2] JOHN MURRAY, 'On the Height of the Land and the Depth of the Ocean', *Scott. Geogr. Mag.*, vol. IV, 1888, p. 1. MURRAY's values were given in English feet and fathoms, but have been referred to metres by A. PENCK, 'Morphol. d. Erdoberfl.', vol. I, pp. 141—142.

[3] For the computation of these values it was supposed that one quarter of the assumed area of the then (1888) unknown parts of the Arctic and Antarctic seas were between 0 and 100 fathoms (0—183 m.) deep. How near this supposition comes to the truth cannot yet be decided, but a possible inaccuracy will have no great influence upon the above values, and will be of little importance for our present purpose.

[4] It is here supposed that about 5 million square-kilometres of the unknown Antarctic region is land, while the whole unknown Arctic region is sea.

Owing to the subaerial erosion, the continental surfaces constantly tend to approach the existing sea-level; but in order to attain an effect such as the above values demonstrate, it seems essential that during very long periods of relatively recent geological history, the sea-level should not have been very different from what it is now[1].

On the other hand there is much evidence to prove that the sea-level or the shore-line cannot have been perfectly stationary during these long periods, even if we leave out of consideration such more local movements of the shore-line as are for instance proved by the post-glacial upheaval of Scandinavia. I may especially mention the following facts.

1) The intermediate position of the shore-line between the outer and inner boundary af the lowlands. It was mentioned above that the shore-line in Norway has an intermediate position between the outer and inner edge of the coast platform, which might seem to indicate that the coast platform was formed during periods when the shore-line has oscillated above and below its present position. It is a remarkable fact that the present shore-line also has an intermediate position between the level of the outer edge of the continental shelf and that of the inner boundary of the continental lowlands, in Europe, Asia, North and South America, and even in Australia, New Guinea, Borneo, Sumatra, and on the west coast of Africa. It is also a striking fact that the drowned plains of the wide continental shelves, often form a nearly direct continuation of the great continental plains, and sometimes may even appear to have been formed in the same way, *e. g.* the shelf of the east coast of North America (see above p. 188). These facts might seem to indicate previous variations of the shore-line. That such changes of the shore-line have occurred, is proved by several conclusive facts.

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[1] Even on the mountainous Scandinavian Peninsula, there is evidence of long periods with sea-levels similar to those of the present day, I may instance the extensive low region — chiefly of Archæan rocks — in southern Sweden (Pl. I), and also in southern Norway (Smaalenene and the south eastern coast, see Pl. XI). These regions have during long periods, evidently been worn down towards a base-level which cannot have differred much from the present sea-level. Prof. BRÖGGER considers it probable that the low Archæan region of Smaalenene, Bohuslän, Halland, etc. indicates an ancient Pre-Silurian plain of marine denudation, which has once been covered by Silurian and Post-Silurian formations; these formations have now been obliterated by erosion. As before mentioned (p. 133), I do not believe much in these extensive ancient plains of marine denudation, but if BRØGGER's assumption be correct, it would prove that even in Pre-Silurian times there was a sea-level, which was very near to the present one.

2) The wide extension of marine sediments on the continental plains prove that the latter have been covered by sea at least once, and generally several times.

3) We have seen above that the level of the eroded parts of the continental shelves cannot have been developed at present sea-level; the shelves must at times have stood nearer sea-level than they do now.

4) The universal occurrence of *submerged dissected coasts* in nearly all regions of the world, indicates also an universal and comparatively modern transgression of the Ocean[1], for it seems highly improbable that nearly *all* coasts could have been simultaneously depressed by tectonic movements.

5) The coral reefs in different regions of the Ocean, seem to indicate a late universal rise of sea-level: The wide distribution of *barrier reefs* with deep and broad lagoons, and with nearly vertical walls ascending from great depths[2], for which it otherwise seems difficult to account, may easily be explained in this way. The fact that such barrier reefs, built up from great depths, occur on continental coasts — *e. g.* in Australia, where they have their greatest extension, and also in Africa, as well as on oceanic islands, proves that their occurrence cannot be due to more or less local volcanic movements. The vertical outer sides, descending to great depths, and the relatively deep lagoons of a great number of *atolls*, distributed over a great area of the globe, are also most simply explained by a universal rise of sea-level[3]. The occurrence of elevated coral reefs with terraces indicating pauses in the vertical movements, does not disprove the above theory; for as will be mentioned below there may have been great oscillations of the shore-line, either local or of a more universal extension.

The above facts prove that there have been oscillations of the shore-line within a vertical range of at least a hundred or a few hundred metres, and

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[1] Cf. A. PENCK, Morphologie der Erdoberfläche, 1894, vol. II, pp. 580—581. As mentioned by PENCK, the greater part of the smooth coasts are low coasts, which have been silted up by alluvial deposits, and they cannot therefore be assumed to be recently elevated coasts; the silting up by alluvials may, in many cases, have fully compensated the submergence of the coasts. The recent, post-glacial upheavels of many coasts (*e. g.* in Scandinavia), which are evidently due to isostatic movements, may mask the above transgression of the Ocean, but they are naturally an entirely different affair.

[2] Cf. PENCK, *op. cit.* vol. II, pp. 593—595.

[3] Cf. PENCK, *op. cit.* vol. II, pp. 658—659.

these oscillations must have had a very wide or perhaps universal extension over the surface of the Earth.

6) The drowned valleys and fjords of the continental shelves and suboceanic continental slopes — *e. g.* the drowned valleys of the Kara Sea, the Barents River System, the Vardø Submarine Channel, the longitudinal valleys of the Norwegian continental shelf, the Færoe-Shetland Channel, the Fosse de Cape Breton, the drowned Kongo Channel, the drowned channels of the St. Lawrence River, the Hudson River, etc. etc. — prove that there have been even much greater oscillations of the shore-line. At least at some places, the shore-line has stood 1200 m. lower than it does now, and probably even much lower.

7) Several suboceanic platforms or terraces — *e. g.* the Blake Plateau, the platforms at depths of about 1200 and 1300 m. to the west and south-west of the Færoes, etc. — seem also to indicate a so much lower situation of the shore-line.

What are the possible causes of these oscillations of the shore-line? Are they due to movements of the lithosphere or to possible oscillations of the hydrosphere, or perhaps to both? Our imperfect knowledge both of the detailed bathymetrical features of the Ocean's bed and of the physics of the Earth makes it very difficult to answer this question.

According to J. W. SPENCER's interesting investigations of the drowned valleys of the Antillean region, there have been many and great vertical oscillations of the shore-line during late geological periods. He believes that these oscillations have been due to epeirogenic movements, and assumes that in neighbouring regions they have frequently not been simultaneous, and may even have often differed considerably in magnitude over comparatively short distances. But this assumption does not seem to harmonize well with the remarkably uniform level of the continental shelf of this extensive region; the greater part of the shelf must, according to SPENCER's own description, have been formed (as a coastal plain) prior to the formation or at least prior to the re-opening of the drowned valleys. He assumes that the shelf was previously even much more extensive than it is now: east of the Bahamas "its broken remains rise in banks north of Haiti and beyond, it has been largely swept away" by denudation, "only fragments of it remaining east of the

Windward Islands, but off the coast of South America it reappears"[1]. If SPENCER's description of the drowned valleys be correct, it is, as far as I can see, impossible that the shelf was formed after the subsidence of the coasts from the last great elevation, for if so the valleys which now traverse the drowned plains of the shelf, and which were re-opened during the last elevation, would have been entirely filled up and obliterated. The drowned valleys now traversing the shelf, have, according to SPENCER, probably been filled up and re-opened several times, according as the shelf has been submerged or elevated above sea-level; but as the continental shelf has still a nearly uniform level throughout the whole region described by SPENCER, it is, I think, impossible that the vertical oscillations of the shore-line, can have been due to more or less local tectonic or irregular movements, a fact which has hitherto hardly been sufficiently appreciated.

On the other hand it seems to me now to be doubtful whether my statements in a lecture, referred to above (p. 100—101), were justified. I said, that "if we can prove that the continental shelf has been emerged into dry land, and at some places has stood perhaps several thousand feet above sea-level, we are simply forced to the conclusion that the shelf has undergone the same oscillations of level along its whole length; and this great change of level must then have been due to oscillations of the hydrosphere; for it would seem inconceivable that the lithosphere should be able to undergo such regular and extended vertical movements or pulsations". This was my view two years ago, but I think now, that there are other explanations, and I do not consider it necessary to assume that the continental shelf has undergone the same changes of level along its whole length — *e. g.* along the Eurasian coasts from Spain to Bering Sea — even though at some places it may have been elevated more than a thousand metres and again lowered to its original position.

The above facts seem to indicate that on the one hand there has recently during very long geological periods been a certain stability of sea-level on the Earth's surface, but at the same time there have also been oscillations of the coasts relative to the sea, and these oscillations have probably been of two kinds: — a) Great oscillation above and below present sea-level, proved by marine sediments on land, and by drowned valleys on the sea-bottom; these

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[1] J. W. SPENCER, *Bull. Geol. Soc., America*, vol. VI, p. 108.

oscillations have occurred at different periods. b) A late and more universal rise of sea-level of perhaps 100 m. or more accompanied perhaps by several oscillations of the same kind; this rise of sea-level is proved by the universal submergence of the continental shelves, the dissected coasts, and coral islands and barriers.

Leaving the latter kind of variations of the shore-line provisionally out of consideration, we will first discuss the possible cause of the stability of sea-level and the great oscillations. There may be many causes of disturbances of sea-level, but it is obvious that a theory which should explain the above facts satisfactorily, must be based on some principle that gives the Earth's surface a strong tendency to return to its original level after disturbances, whether these be disturbances of the lithosphere or the hydrosphere; for it cannot be merely accidental, that the universal oceanic level, relative to the land surfaces, is now approximately the same as it has been during very long geological periods, in spite of the great oscillations of the shore-line, which have occurred, at least at some places. Thus a great many possible causes of changes in the relation between the level of the sea and the land may be discarded as explanations of the above oscillations of shore-line.

We have seen above (p. 128) that the coast platform of Norway, between Lindesnes and Finmarken, stands at a nearly uniform level although, since the formation of the platform, the coast has been very differently depressed, probably by the weight of the inland ice[1]. The continental shelf shows a similar feature: Although the post-glacial upheaval of the outer coast of Lofoten-Vesteraalen has been only 10 or 20 m., the continental shelf there stands at about the same level as off the Romsdalen coast where the post-glacial upheaval is between 60 and 90 m. This shows that the Earth's crust has probably a remarkable ability to resume after a while its original position of equilibrium, when the original conditions are re-established. If it be assumed that

[1] Some geologists have tried to explain the glacial depression and the post-glacial upheavel of the glaciated lands by the cooling effect of the inland-ice on the underlying ground. But this explanation is not feasible; for in Arctic lands, — *e. g.* Franz Josef Land, Spitsbergen, Northern Greenland, Siberia, etc. — the inland-ice must have caused a rise of temperature in the underlying ground, and there are nevertheless post-glacial elevations of land similar to those in more genial regions.

the Earth's crust floats on the heavier underlying magma[1], like the polar ice floating on the Polar Sea, it might seem quite natural that such should be the case. An extensive polar ice-floe loaded at one place by heavy ice-pieces, will in the course of time gradually bend at this place under the load, and will go on being depressed until it shall have attained a new position of equilibrium. If the ice-pieces be again removed, the depression of the floe will be gradually lifted by its boyancy, until the floe regains its original position of equilibrium, provided that the thickness has not been altered during its depression into deeper water-layers. If a great floe be exposed to tangential pressure, "icepressures", it may be warped or tilted in different ways, and may thus be more or less removed from its position of equilibrium. But if the pressure necessary to keep it in such an unstable position be reduced or cease altogether the floe will tend to slowly approach its former position of equilibrium and in the course of time it may gradually regain it.

The Earth's crust probably behaves in a similar manner, and even though by tangential pressure, by seismic strains, or by other forces, the continental coasts may have been more or less locally depressed or elevated below or above the crust's natural position of equilibrium, it seems probable that when the pressure ceases, the latter will in the course of time gradually be regained. If the tangential pressure has caused a mountain formation near the place, the new position of equilibrium may naturally differ much from the former

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[1] The Earth's crust is probably composed of rocks which have a lower specific gravity than the underlying magma. It seems probable that before the crust was formed the upper layers of the hot flowing magma were lighter than the deeper layers, just as in the North Polar Basin the upper water-layers are much lighter than the underlying ones and thus ice may there be formed on the surface in spite of the fact that sea-water has its minimum volume at a temperature much below freezing-point. Thus it may be explained how a solid crust could be formed on the surface of the fluid magma, in spite of the fact that the magma contracts by cooling, and most known rocks contract when they are solidified at pressures which prevails near the Earth's surface. It seems also probable that the majority of the rocks of the crust have a higher melting point than the underlying magma, and therefore they were first solidified during the cooling of the Earth's surface, and having a lower specific gravity they would float on the heavier magma.

It is probable that at sufficiently high pressures the rocks do not change their volume during solidification, and at still higher pressures they even expand like water, when they pass from a fluid or semi-fluid to a solid state; but we should probably be obliged to go far below the base of the solid crust of the Earth to find such pressures. Although this property of the known rocks cannot therefore help to explain the floating of the crust on the magma, it is very important to prove that the Earth's interior cannot be solid but must be gaseous, as has been pointed out by ARRHENIUS.

one, this will be much like the formation of pressure ridges and hummocks in the polar ice: the folds and crests formed, may by their weight, press down the crust, or if great masses are pressed down under the crust the latter may be lifted by the boyancy. But the formations of mountain chains are more local and comparatively rare phenomena, and have therefore no bearing on the level of the continental coasts in general.

The thermal contraction and expansion of the rocks of the Earth's crust, due to changes in temperature, must by the accompanying changes of specific gravity naturally affect the crust's position of equilibrium, and will consequently cause slow regional depressions or elevations of the crust. These movements may be much increased by the circumstance that most rocks contract when solidified at pressures no greater than those prevailing within the Earth's crust. If masses of fluid magma be enclosed as vesicles in the crust at greater or smaller depths below the surface, a lowering of the crust's temperature might solidify more or less of this enclosed magma, and the consequent contraction of the crust in this region will make the crust sink slowly into the mass of underlying magma. The changes of level thus produced may have more or less permanency until the original temperature be perhaps re-established; but in somewhat different manner more oscillatory changes might be caused. If the temperature at the underside of the Earth's solid crust be lowered at some place, the underlying fluid or semi-fluid magma may be solidified to some extent, and if the solid rocks thus formed adhere to the crust, the latter may sink deeper into the magma at this place[1]. Another process is, however, possible: gradual cooling may produce slow vertical currents in the magma, and the sinking, cooled magma, being exposed to greater pressure, may be solidified at some depth below the crust; in any case a contraction of the mass is produced, which will cause a depression of the crust; as the weight of the mass is increased by the reduction of the distance from the Earth's centre of gravitation the pressure in the magma is increased, and more of it may be solidified. If by this depression the surface of the crust be submerged under sea-level, the pressure is still more increased by the weight of the increasing thickness of water; and be-

[1] If, however, the magma be differentiated more or less during solidification, and the lighter compounds be first solidified, having a comparatively high melting point, it may have the opposite effect and may tend to raise the crust.

sides, by the contraction of the mass and the accumulation of water, the gravitation of the region is increased which will cause an additional accumulation of water and an additional increase of pressure. It would lead us much too far to follow these processes into detail, it is sufficient here to point out that a change in the relations between land and sea may be thus produced in this region; but at the same time the state of equilibrium has been disturbed in the magma underlying the crust, and there will be a tendency towards a slow influx of fluid from other regions of the magma to this region; this influx will, however, occur after the contraction of the magma produced by the cooling and increase of pressure, and it may thus cause a gradual upheaval of the crust after it has been once depressed; by this upheaval the weight of the crust and the pressure on the magma are reduced by the increased distance from the centre of gravity. This pressure is still more reduced by the removal of the Ocean waters due to the upheaval of the Ocean floor; some part of the solid rock in the magma, or on the underside of the crust, must assume the fluid state under this reduction of pressure; by the expansion of the mass thus produced, the upheaval will be increased, the pressure will be reduced, and more solid rock will become fluid, etc. I shall not go further into detail, what has been said is perhaps sufficient to show that a vertical oscillation of the lithosphere may be caused in this way, and the crust will have a tendency to approach its former position of equilibrium, the new position will only be so much lower as the specific gravity of the crust has been increased by the cooling.

If the temperature of the crust be raised, changes of level in the opposite direction will be produced, and similar oscillations of level will arise, until the new position of equilibrium is attained.

If the original temperature of the Earth's crust be re-established — after a rise or fall of the temperature, — it seems probable that after the elapse of the necessary time the crust would regain its original position of equilibrium.

That great changes of temperature have occurred at many places on the Earth's surface during recent geological periods is certain. I may instance that during Tertiary and Cretaceous times the climate in northern Greenland, in 70° N. Lat., was 20 or 30° C. warmer than now. Besides, chemical processes in the upper strata of the Earth's crust may greatly influence its temperature.

I may also mention that in the Tropics, the mean temperature of the continental surface is at least 20 or 25° C. warmer than that of the deep-sea bottom, whilst in the Polar regions it is just the opposite the mean temperature of the frozen ground of northern Siberia is about 16° C. lower than that of the submerged continental shelf. The submergence of a continental surface under the sea may therefore cause great changes in the temperature of the crust.

If the temperatures at the Ocean bottom be compared with those at similar depths below the continental surfaces, we shall find remarkable differences: Provided that the temperature of the Earth's interior rises 3° C. for every 100 m. of depth, there would be a temperature of about 115° C. at 3000 m. below the surface of a tropical continent, *e. g.* Africa, with a mean surface temperature of 25° C.; on the Ocean bottom at a similar depth the temperature is only some degrees above freezing point; the difference of temperature at this level below sea and under the continent is consequently more than 100° C. At 6000 m. the corresponding difference will be about 200° C.; and the difference between the temperature at the bottom of the greatest Ocean deeps of more than 9000 m., and that at a similar depth below the continents will be more than 300° C.

It is obvious that temperature-differences such as these at depths of 3, 6, and 9 kilometres must also cause great differences in the temperatures at 40 or 60 kilometres below the surface of the spheroid, where they should be about 1200° C. or 1800° C. underneath the continents, but must be much less below the deep Ocean. Provided that the Earth's crust is no thicker, the fluid magma under the deep Ocean must be cooled rapidly below its melting point, and a solidification of magma and a considerable contraction must consequently occur; it is, however, probable that the under side of the crust lies deeper under the Ocean than under the continents. However this may be, it seems obvious that a considerable cooling of the Earth's crust must take place under the deep Oceans, especially in the warmer regions; and if a continental surface be once submerged under sea-level, it may have a tendency to remain there and even sink deeper owing to the cooling of the crust. A regional sinking of the Ocean bottom in this manner will naturally have a universal effect

upon the level of the hydrosphere[1], but unless we assume that this movement of the sea-bottom is oscillatory, the above oscillations of the shore-line cannot be explained in this manner. The filling up of the Ocean basins by sediments may again raise the sea-level after it has been thus lowered, but I do not see how it can act sufficiently regularly to explain the great stability of a mean sea-level during recent geological periods. And furthermore the deposition of sediment on the Ocean bottom is too slow to explain the great changes of level in recent times, indicated by the drowned valleys. There is also the difficulty that the greater part of the terrigenous waste is deposited near the coasts, and if the rise of sea-level after the formation of the drowned valleys should be thus explained, it seems difficult to understand why the valleys have not been entirely filled up and obliterated.

On the other hand it is obvious that the filling up of the oceanic basins by sediments, which originate from the surface of the continents must in the course of time influence the level of the Ocean as well as the equilibrium of the Earth's crust. If we assume that the changes of sea-level thus produced are more or less compensated by the sinking of the Ocean bed, due to the load of the sediments, and the rise of the continents, due to the stripping by erosion, this will explain very little, for if there have been no other epeirogenic movements of the continents or the lithosphere (or the hydrosphere), it seems inconceivable why the continents have not been long ago stripped of all sedimentary rocks outside the mountain regions. It is clear that erosion and sedimentation must in the course of geological time have caused great changes in the relation between land and sea; but I shall not go further into these details here, it is sufficient to point out, that there cannot have been great changes of sea-level caused by sedimentation after the time when the present continental shelves and plains were developed.

If in recent geological periods there have been forces which have tended to change the spheroidal form of the Earth, they may have first caused movements of the hydrosphere and afterwards of the lithosphere; these move-

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[1] This effect will probably after a while be somewhat checked by the circumstance that the lowering of sea-level will reduce the pressure on the sea-bottom in other regions of the Ocean, and the bottom will there slowly rise a little. The reduction of pressure may also transform some of the rock on the underside of the crust to the fluid state, and this may raise the sea-bottom still more, provided that this deepeste rock was heavier than the underlying magma.

ments have been independent of the movements mentioned above, and may have produced more or less regular oscillations of the shore-line. Such changes of the Earth's spheroidal form may have been caused by changes of the Earth's centre of gravity, by changes in the Earth's period of rotation, and by changes in the position of the Earth's axis of rotation.

We know very little of the nature of the gases constituting the Earth's interior; but it seems hardly probable that they have attained a state of perfect mutual equilibrium, and if such a state be attained it may be disturbed *e. g.* by the cooling of the Earth, or by changes in its elipsoidal form due to retardation of the rotation, etc.; it seems therefore possible that chemical processes of some kind, or other changes may take place. In this manner appreciable movements of the Earth's centre of gravity may occur in the course of time, and this will again affect the form of the spheroid.

According to computations made by G. H. DARWIN the age of the Earth should only be 57 000 000 years[1]; its period of rotation was then only 5¾ hours, but had increased to 15½ hours after 10 000 000 years. If his curve be continued, we find as maximum values of the period of rotation about 19½ hours 25 000 000 years ago, and about 22½ hours 10 000 000 years ago. Even if these changes in the period of rotation be somewhat reduced, it is seen that within comparatively recent times geologically speaking, the rotation of the Earth has been considerably altered, which has had an appreciable effect upon its spheroidal form. As, however, the change has probably been very slow and regular, it is hardly probable that it has been able to cause any regular oscillatory movement of the shorelines, it seems more probable that while the hydrosphere has immediately followed the change, the lithosphere has much more slowly but regularly accomodated itself to the new, less elipsoidal form conditioned by the slower rotation, and thus no great movements of the shore-line, may have arisen, although there may have been a general tendency towards emergence of coasts at low latitudes and a subsidence at high latitudes. As, however, the less elipsoidal shape has a smaller surface than the more elipsoidal, provided that the volume remains the same, the above changes must produce a tangential pressure in the Earth's crust, differing in its effects somewhat from those forms of tangential pressure which are

[1] This figure, however, is probably much too low.

due to contraction of the Earth's interior, and to regional changes in the temperature of the Earth's crust.

Neither from an astronomical nor from a physical point of view can it be denied that the position of the poles on the Earth's surface may have been changed appreciably in geological time, and several geological facts as well as some features of the present morphology of the Earth's surface — *e. g.* the situation of the mediteranean depressions — have been pointed out by some authorities as indicating probable movements of the poles. How great these possible movements may have been cannot be decided, but it is obvious that they would cause oscillatory movements of the shore-lines, as would also movements of the Earth's centre of gravity; for, although the crust actually yields to pressure, as is proved by its tidal motion produced by the attraction of the moon, it is probable that the rigidity of the crust and the great internal friction of the magma and the gases of the Earth's interior would allow the lithosphere to assume the form conditioned by the new position of the axis or the centre of gravity, only extremely slowly and only after a long time. The hydrosphere would, however, at once assume the new form, and for a while movements of the continental shore-lines would thus be caused[1] until the crust had had the necessary time to attain its new position of equilibrium, when the original relation between land and sea would be approximately re-established.

We thus see, that even though forces in various forms may have tried to disturb the present relation between the Ocean and the continents, the great changes of the shore-lines caused by some of these forces may have lasted only for a time, as the Earth's crust will have a tendency after each disturbance to re-approach its position of perfect equilibrium, determined by the boyancy of the crust floating on the underlying magma[2]. Thus it is conceiv-

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[1] *Van de Sande Bakhuysen* has pointed out that the observations of water-level in the harbour of Helder, from 1855 to 1892, actually show changes of sea-level which coincide with the changes in the situation of the pole.

[2] As after each disturbance the crust approaches its position of equilibrium asymptotically, the shore-line will stand only slightly above or below the mean position during the greater part of the time. and thus the levels of the shelves and plains might be explained.

As the thickness of the Earth's crust slowly increases owing to the secular cooling, it might be expected that it would be deflected from its epuilibrium with increasing

able that the level of the Ocean, in spite of temporary changes, has been the same as to-day during long recent geological periods, as is proved by the continental plains and shelves.

The above theory of a tendency towards a position of perfect equilibrium in the Earth's crust explains why the extensive plains and shelves of the continents only occur near present sea-level. If it were not so, we might equally well expect to find similar extensive plains at other higher or lower levels, considering the fact that the Earth's crust has been subjected to great vertical movements. Nevertheless we have seen above that there are remarkably concordant indications of certain very low sea-levels, which may once have existed simultaneously, at least in comparatively great areas of the Ocean. I may especially draw attention to two different levels on the bottom of the northern seas which seem to occur at many places:

The one level is indicated by the depth of about 500 m. of the great submarine fjords of the Barents Sea, Norway, the North Sea, probably the Færoes, Iceland, Greenland, and Canada, and the depths of the great submarine ridges between Scotland, the Færoes, Iceland, Greenland, and Baffin Land. As was mentioned above (p. 173) it is according to my view, probable that this remarkably coinciding depth of about 500 m. indicates an ancient sea-level which prevailed simultaneously in this extensive region.

Another greater depth of about 1200 m. occurs in a rather striking manner in the deep submarine depressions as well as on the submarine plateaus of the Norwegian Sea and the Northern Atlantic. We have seen that the nearly horizontal bottom of the remarkable *Færoe-Shetland Channel* as well as the channel south of the Wyville Thomson Ridge, lies very nearly at this depth for a distance of more than 500 kilometres. The deep gully off the south-east coast of Iceland (Pl. XXIV) has the same depth. At the mouth of the *Laurentian Submarine Channel* and off the *Gulf of Maine* there are coves in the edge of the continental shelves with similar depths (1117 and 1244 m., see pp. 97—98). In the Antillean region, according to SPENCER, si-

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difficulty (longer time and longer "lag") and with diminishing amplitude, so that from the earliest times of the Earth's history the undulations of the "pulsation" curve have been gradually decreasing, and we may expect to find greater oscillations in the relation between land and sea, the farther we go back, which is hardly incompatible with known geological facts.

milar depths are very common in the submarine channels. On the edge of the continental shelf off the English Channel there are several deep coves with soundings of 1037 m., 1454 m., 1262 m., and 1116 m. (see above p. 94). The *Fosse de Cape Breton* is for a distance of 18 kilometres from 1120 to 1160 m. deep. In the region south and west of the *Fœroe Bank* there seem to be extensive submarine plains at depths between 1100 and 1300 m. (se above p. 73). The *Reykjanes Submarine Ridge* extending south-west from Reykjanes (see p. 85) seems to lie at depths of between 1230 and 1265 m. for great distances. The *Faraday Hill* rises to within 1145 m. of sea-level. The *Vöring Plateau* in the Norwegian Sea (see pp. 53—54) lies possibly between 1260 and 1423 m. The edge of the *Blake Plateau* off the American east coast lies between 1000 and 1200 m. (see p. 97). It is also worthy of note that "a very remarkable terrace is found running for a considerable distance along the western part of the Guinea Coast, at a depth of from 600 to 700 fathoms (1100—1280 m.) from the surface"[1]. It may also in this conection be mentioned that the deepest fjord of Norway — the Sogne Fjord — is about 1240 m. deep, although this depth may be accidental, as it is probably due to glacial erosion.

If the above approximate coincidence of depths of about 1200 or 1300 m., and 500 or 600 m. over extensive regions of the Ocean's bed, are not merely accidental, which seems hardly probable, they may indicate ancient sea-levels which had vast extensions, and I consider it probable that the above mentioned submarine channels and coves, are ancient valleys of erosion, which have been cut down towards base-levels during periods with such sea-levels. The submarine plains may be remains of continental shelves formed simultaneously. We could hardly expect that the levels of the ancient channels and submarine plains should be very uniform now, as the deposition of sediments may have differed much at the several places; and besides we have seen above, that even the level of the present continental shelf may differ as much as 150 m. or more, even in neighbouring regions.

It might, however, be difficult to find a feasible explanation of such extensive and regular changes of sea-level. Movements of the poles of the Earth, will naturally have a universal great effect on sea-level, but this effect would

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[1] J. Y. Buchanan, *Scott. Geogr. Mag.*, vol. III, 1887, p. 230.

differ much in various latitudes. If for instance the North Pole has been moved to its present position from a place which is now in 85° N. Lat. and 175° E. Long., and provided that the lithosphere maintained its former spheroidal shape for some time after the movement of the pole, this would cause a temporary fall of sea level of:

Temporary Fall of Sea-Level	Latitude.	Place
about 790 m.	in 80° N. Lat.	in Spitsbergen
- 1060 -	- 75° - -	near Bear Island
- 1320 -	- 70° - -	northern Norway
- 1530 -	- 65° - -	east coast of Iceland
- 1690 -	- 60° - -	Shetland Island
- 1800 -	- 55° - -	west coast of Iceland
- 1850 -	- 50° - -	near English Channel
- 1850 -	- 45° - -	Bay of Biscay
- 480 -	- 10° - -	west coast of Africa
- 160 -	- 5° - -	- - - -
- — 160 -	- 0° - -	- - - -
- — 480 -	- 5° S. Lat.	near mouth of Congo

In the above rough calculations the changes of gravitation due to the temporary displacement of the hydrosphere has not been considered. The temporary fall of sea-level would probably not be as great as in the above table; for the lithosphere would certainly yield to the pressure and change its form somewhat, simultaneously with the movement of the pole, just as it yields to the attraction of the moon. However this may be, it is seen that the apparent uniformity of the possible ancient sea-levels at about 500 and 1200 m. below present sea-level can hardly be explained by changes of level due to movements of the pole, at least not if we assume that the changes were fairly uniform off the Gulf of Guinea and in the Northern Atlantic. Changes of the Earth's centre of gravity might more easily explain such uniform oscillations of sea-level over extensive regions, as they would cause displacements of the whole hydrosphere. A great sinking and subsequent elevation of the Ocean bottom in some region, — *e. g.* in the Pacific Ocean — might also produce a great fall and rise of the Ocean relative to the land, which would be fairly uniform in great parts of the Atlantic.

Variations in the volume of the hydrosphere would naturally cause fairly uniform changes in sea-level; but we know no agencies which might have produced such very great changes in the volume of the Ocean within a reasonable time, as would be necessary to explain the above great oscillations of the shore-line. And besides, there is the difficulty that the process causing the changes of volume must have had an oscillatory effect, for else we cannot explain why the surface of the Ocean has stood near present sea-level during the greater part of recent geological time, in spite of all great oscillations.

The apparent rise of sea-level in nearly all regions of the Ocean, indicated by the submergence of the eroded continental shelves, the general distribution of submerged dissected coasts, the recent subsidence of coral atolls and coral reefs, etc. (see above p. 197), may perhaps most simply be explained by a recent increase of the water-volume of the Ocean. We know that variations in the latter must have been caused by the accumulation of ice on land during the glacial periods[1], it is, however, difficult to calculate the possible magnitude of these variations, as we do not know the average thickness of ice-sheets and the area which they simultaneously covered. PENCK mentions that during the glacial period in North America an area of 20,721,000 square-kilometres, and in northern Europe 7,138,000 square-kilometres were ice-covered. If the mean thickness of the ice were 1 kilometre, the volume of the Ocean was thus reduced by 25,630,000 cubic-kilometres of water, which would make its level sink about 71 m.[2]. If, however, we take into consideration that in many mountainous regions farther south there were great accumulations of ice, and that the continental shelves were probably also covered by ice, during its greatest extension, perhaps as far north as Spitsbergen, and if moreover, we assume that great parts of Siberia were covered by ice simultaneously, the area of the ice-covering might possibly be increased by a half, and the lowering of the sea-level may well have been as much as 100 m. instead of 71 m. But if the mean thickness of the ice were 1·5 kilometres instead of 1 kilometre, the sea-level may have been lowered 150 m. or still more, especially when we consider the great reduction of the area of the Ocean at this level. If it be more-

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[1] Cf. H. HERGESELL, *Gerlands Beiträge zur Geophysik*, vol. I, 1887, p. 59. E. von DRYGALSKI, *Zeitschr. Gesellsch. f. Erdkunde*, Berlin, vol. XXII, 1887, p. 169. R. S. WOODWARD, *Bull. U. S. Geol. Survey*, No. 48, Washington, 1888.

[2] PENCK, Morph. d. Erdoberfl., vol. II, p. 528.

over assumed that the northern seas were filled with much more ice than now, which floated with one ninth or one tenth above water, and that the ice-masses in the Antarctic region were simultaneously much greater than to-day, it might well be conceivable that the level of the Ocean was at times lowered as much as 200 m. or even more. But on the other hand, we do not know whether the glacial periods were simultaneous in these different regions, and this might even seem very doubtful. However this may be, it seems certain that during glacial periods the oceanic level was lowered to some extent, and the melting of the masses of land-ice must have raised the level of the Ocean. On the other hand, the reduction of the volume of the Ocean may have caused a rise of the bottom, owing to the reduction of pressure, while the return of the water-masses to the sea may again have caused a depression of the Ocean's bed by the increased pressure, and in this manner the apparent changes of sea-level on the coasts may gradually have been somewhat reduced.

Even though a recent general rise of sea-level has been caused in this way, it is very doubtful whether the submergence of the eroded continental shelves may be thus explained. The continental shelves were chiefly formed in pre-glacial times, and might thus be expected to mark pre-glacial sea-levels, existing before the above variations. We should be obliged to assume that the levels of the shelves have been more or less lowered during the glacial periods of low sea-level. But it might seem doubtful whether these periods lasted sufficiently long to produce such effects, and besides in the glaciated lands, *e. g.* in Norway the continental shelves were probably lowered by the weight of the ice, and although this depression of the land was much slower than the fall of sea-level, it would essentially shorten the periods of low shore-lines. It seems, however, as if on the Norwegian coast the periods, when the continental shelf was worn down to its lowest levels, have had no very long duration, for else it can hardly be explained why the regions of hard Archæan rocks — Romsdalen and Lofoten-Vesteraalen-Senjen — have not been worn down to nearly the same low levels as the other parts of the continental shelf.

A slight rise of sea-level in modern times may naturally also have been caused by the deposition of sediments on the sea-bottom, but it has to be considered that the greater part of the terrigenous waste carried into the Ocean is deposited near the coasts and aids in building up the continental shelves. It seems therefore improbable that the rise of sea-level, caused by sedimen-

tation, should be more rapid than this growth of the shelves, even if we take into consideration the local increase of gravitation caused by the deposits themselves. A slight subsidence of the eroded parts of the continental shelves may, however, be explained in this way, if they stand so near sea-level that the movements of the water prevent any appreciable sedimentation on them.

SUMMARY.

The chief results of the above discussion may perhaps be thus summarized:

On the one hand there have been small and great oscillations of the shore-line during late geological periods, but on the other hand there has, during long recent geological periods, been a remarkable stability of the shore-line near a certain mean level, as is indicated by the extensive plains and shelves of the continents standing between 200 m. above and below present sea-level. Whatever the causes of the oscillations of the shore-line may have been, the above facts seem to prove that, after each disturbance in the relation between land and sea, the Earth's crust has a remarkably strong tendency to return to a certain position of perfect equilibrium, which is probably determined by the boyancy of the crust floating on the underlying magma.

XI. THE BOTTOM DEPOSITS OF THE NORTH POLAR BASIN.

The bottom deposits of the North Polar Basin will be described by Mr. O. B. Bøggild in Memoir No. 14; in so far as they may throw some light upon possible changes of sea-level in this region I may also discuss them briefly here. The deposition of terrigenous waste is largely influenced by the depth of the sea and the distance from land, as it is of course also dependent on the velocity of the bottom waters. If there have been great oscillations of the shore-line it seems therefore probable that they may have affected the sedimentary conditions, at least in the sea near the continental shelves; we must therefore expect to find some stratification in the bottom deposits of this region, and this is actually the case, in the North Polar Basin, the Barents Sea, and in the Norwegian Sea.

As is mentioned by Mr. Bøggild the colour of the bottom sediments may give some information as to the rapidity with which they have been deposited. As the brown colour of the deposits is due to ferric oxide (Fe_2O_3) which is extremely slowly formed on the surface of the mineral grains lying in sea-water, it is understood that brown clay and sand deposits must have been formed much more slowly than grey deposits[1]; in the latter case the grains

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[1] The fact that the deposits of the North Polar Basin have a brown colour in spite of their remarkably small percentage of carbonate of lime and other components due to organic life, disproves the theory that "the higher degree of oxidation distinguishing Biloculina clay (of the Norwegian Sea) — and to which its brown colour must be ascribed — may arise from animal life" (see L. Schmelck, 'Chemistry', p. 71, *The Norwegian North-Atlantic Expedition 1876—78*). Schmelck himself has, however, at another place (*l. c.* p. 48) said that we might "not unreasonably infer that the greater or less extent to which a deposit is oxidized mainly depends on the length of the period during which it has been lying at the bottom of the sea".

have not had sufficient time to become brown before being covered by new layers of grains protecting them against the action of the sea-water. If therefore, in a particular region of the Ocean we find the bottom deposits composed of an upper layer of brown clay resting on grey clay or *vice verca*, it indicates that the conditions of sedimentation have been essentially changed in this region. It has been assumed that such changes of the sedimentary conditions may have been due to climatic changes, since more waste may have been carried into the sea during a period of humid climate or during a glacial period than during a dry one. It seems, however, to be equally probable that the above differences in the colour of the deposits may in many cases have been due to movements of the shore-line in the region, by which the distance of the sea-bottom from land may have been much changed, and further the drainage area of the rivers and the height of the land above sea-level may have been altered, and so have influenced the amount of waste carried by the rivers. It is evident that even comparatively small movements of the shore-lines may in this way have a considerable effect, especially in a shallow sea with an extensive lowland inside — *e. g.* the Siberian Sea —, whilst where the land is high with a steep coast and a comparatively steep descent towards the oceanic deeps a moderate upheaval or sinking of the land, or the sea-level, might make no very great difference horizontally, in the situation of the coast.

The bottom deposits on the Siberian continental shelf were composed of grey sand and clay, whilst those of the deep North Polar Basin were of brownish deep-sea clay. But on the steep continental declivity, at a depth of about 1400 m. just beyond the edge of the continental shelf, to the north-west of Kotelnoi (on October 4th, 1893, see above p. 9) we found an upper layer of grey clay, 10 or 11 cm. thick, resting on brown clay; the boundary between the two layers was sharply defined. In the upper grey layer H. KIÆR (see Appendix II) found no Foraminifera, whilst in the brown underlying layer he found *Reophax difflugiiformis* and young specimens of *Nodulina* rarely occurring. No conspicuous difference in the chemical composition of the two layers has been found (see Appendix I), and what is especially remarkable is that the percentage of lime is much the same. The difference in colour seems

to indicate a change in the rate of deposition of the sediments[1], and in my opinion, this change may probably have been due to a comparatively recent upheaval of the land to the south, by which the continental coast has come much nearer, and the New Siberian Islands and probably a great part of the continental shelf have been raised above the water-level. It seems at any rate improbable that this change of sedimentary conditions can have been due to changes of climate; for the grey upper layer should then indicate a recent change towards a more humid climate, whilst Siberia has at present an extremely dry climate, and it seems hardly probable that its precipitation has formerly been much less.

The recent upheaval of the Siberian coast, observed by us[2] and others, is probably sufficient to cause considerable horizontal changes in the situation of the coast. The recent movements of the shore-line in Siberia have unfortunately been very imperfectly examined and we do not know their maximum value. We may, however, assume that an extensive area of the northern Siberian Tundra has been submerged comparatively recently; and a subsidence of this lowland of no more than 100 m. or say 150 m., would submerge the greater part of the New Siberian Islands and would move the continental coast east of the Taimur Peninsula a great distance southwards; the drainage area of the north Siberian rivers would be much reduced. It seems probable that changes such as these would much reduce the rate of sedimentary deposition on the sea-bottom at the point of our sounding of October 4th, 1893, and the deposits formed during such a period of great submergence may have had time to become brown by oxidation, while during a later period of elevation the sedimentary deposition at this place was more rapid; whether this period still exists is perhaps difficult to decide, but I consider it more probable, that it was when the shore-line was lower, and the coast was still further north than it is now. This would seem to be in better harmony with the fact that the deposits on the Siberian continental shelf vary in composition even far

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[1] It is very strange that the analyses have no distinct difference in the relation between Fe_2O_3 and FeO in the two layers; the reason may be, however, that the samples had been kept in a dry state for several years, when they were analysed by Dr. HEIDENREICH, and a great amount of FeO may then have been oxidized. L. SCHMELCK mentions one case in which a similar oxidation of samples of Rhabdammina clay probably occurred (*l. c.* p. 44).

[2] See above pp. 102—103.

from land (see above p. 18, footnote 1), which might indicate that the shelf cannot lately have been covered by much deposit.

The bottom deposits of the Barents Sea indicate a comparatively recent change in the sedimentary conditions, which seems to be very similar to that observed at our Station of October 4th, 1893. According to LUDVIG SCHMELCK (*l. c.* p. 43) the bottom of the Barents Sea, between Bear Island and Finmarken and eastward beyond the most eastern stations of the Norwegian North Atlantic Expedition, is covered by a very thin upper layer of green clay, the socalled *Rhabdammina clay*, resting on grey clay. The green clay contains much more FeO in proportion to Fe_2O_3 than does the underlying grey clay; it is consequently much less oxidized than the latter. We have also here an extensive shallow sea where comparatively small vertical oscillations of the shore-line may greatly change the position of the coasts. It is worthy of note that many small stones were often found in the Rhabdammina clay (see SCHMELCK, *l. c.* p. 27, Stations 272—279).

The bottom-deposits of the deep Norwegian Sea show an entirely different stratification; there a layer of *brown* much oxidized clay is resting on a *grey* and less oxidized clay. There is a remarkable and conspicuous difference of composition between these two layers besides the colour: The "*grey underlying clay* is fine, homogenous, and plastic, and becomes on being dried exceedingly firm and cohesive; it contains no animal remains and the amount of carbonate of lime is inconsiderable (1—2 per cent). With the aid of the microscope, minute crystalline particles (possibly quartz) may be detected, which do not become distinctly visible till magnified five or six hundred times"[1].

The *brown clay* (transition clay and Biloculina clay) forms a comparatively thin surface layer covering the grey clay, generally at depths greater than 900 m. (500 fathoms). On the continental slopes this surface layer is very thin, and its thickness increases only very slowly towards the oceanic deeps. In the transition clay, on the continental slope, *Biloculinæ* and other deep-sea Foraminifera occur, but scattered; the percentage of carbonate of lime is therefore also comparatively small. In the real Biloculina clay, shells of Foraminifera, *Biloculinæ* and *Globigerinæ*, are fairly common, and the amount of carbonate of lime generally varies between 15 and 50

[1] L. SCHMELCK, *l. c.* p. 54.

per cent. "On examining under the microscope Biloculina clay from different localities, the fineness of its constituents is not always found to be the same. In some samples, even when highly magnified, it is hardly possible to distinguish the individual particles of which they consist: a number of crystalline granules, here and there varying in colour, may, however, be generally detected with a powerful lens". "Coarser granules, visible for the naked eye, occur very rarely if ever in Biloculina clay, whereas in transition clay such particles, of a rounded form, are not infrequently met with"[1]. The latter difference between the transition clay and the Biloculina clay is probably due to the difference in depth and distance from land; and so is probably also the different amount of Foraminifera (or carbonate of lime) most simply explained, the bottom-currents on the continental slope may be too rapid for the dead shells of Foraminifera to settle there in any great amount.

"In certain localities, the surface layer of Biloculina clay was found to be exceptional in formation: a fine brown clay without calcareous shells constituted the upper part of the sample, whereas the under layer consisted of a porous clay containing great numbers of Foraminifera"[2].

This peculiar stratification of the bottom deposits of the Norwegian Sea, obviously indicates remarkable changes in the sedimentary conditions of this region during recent geological periods. The grey underlying clay must evidently have been deposited during a former period, when there was a comparatively rapid deposition of fine terrigenous waste on the bottom of the present deep basin, and when there was very little animal life. As far as I can make out from SCHMELCK's description, the grey underlying clay may be coarser than the mineral constituents of the brown clay, and it may also be coarser near the continental slopes than farther away from land, it may even contain stones. At Station 285, 73° 6′ N. Lat., 11° 56′ E. Long., depth 1024 fathoms (1873 m.), there was for instance "a brown transition clay on a layer of grey clay, the latter containing two pebbles of sandstone (the largest weighing 4 grams)". During a later period, when the brown clay was formed, the rate of deposition of terrigenous waste must have been much slower, and during this period there has probably been more animal life, although the much greater

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[1] L. SCHMELCK, *l. c.* p. 52.
[2] L. SCHMELCK, *l. c.* p. 54.

amount of Foraminifera and carbonate of lime in the sediment may be explained to some extent by the much slower deposition of terrigenous waste. Besides the above changes in the sedimentation, it seems also possible that there has been a quite recent period when the amount of Foraminifera has been much less, and during this period the surface layer of fine brown clay without calcareous shells observed in some samples, may have been formed.

As far as I can make out from SCHMELCK's and BØGGILD's descriptions and Dr. HEIDENREICH's analyses of our samples there seems to be no essential differences in chemical composition between the terrigenous constituents of the different samples, from the North Polar Basin and the Norwegian Sea, but there may be more difference in the size of the grains. To judge from SCHMELCK's description, quoted above, the grains of the grey underlying clay may have been larger than those of the Biloculina clay, for in some samples of the latter even when highly magnified, it was hardly possible to distinguish the individual grains. The grey underlying clay appears to be more like the deposits of the North Polar Basin in this respect.

The above changes of the sedimentary conditions of the Norwegian Sea may in my opinion most easily be explained by changes in the relation between land and sea. The grey underlying clay may have been deposited during a period when the shore-line in the region of the Norwegian Sea stood much lower than now. The submarine ridge from Scotland to Greenland may then have been more or less elevated above sea-level, thus excluding the warm Atlantic currents from the Norwegian Sea, which might have been more or less covered by ice; the animal life was therefore reduced to a minimum[1]. As the continental shelves of the surrounding lands, Scandinavia, Barents Sea, Spitsbergen, Greenland, Jan Mayen, Iceland, and the Færoes were elevated above sea-level, the area of the land would be much extended, whilst the area of sea was much diminished, and as the height of the land was simultaneously increased, as well as the drainage area of the rivers, it is probable that more waste was carried into the sea, and the deposition of sediments on the sea-bottom thus essentially increased. It seems also possible that at least during

[1] Cf. what is said about the influence of an ice-covering on the sea surface upon the conditions of animal life, in Memoir No. 9, vol. III, p. 422.

some parts of this period, the lands were covered by inland-ice and much glacial detritus was carried into the sea.

When the shore-line rose, the Færoe-Iceland ridge was submerged, the warm Atlantic currents got access to the Norwegian Sea, the extension of the floating ice was reduced, and the biological conditions were much improved, at the same time the deposition of sediments in the deep parts of the sea became much slower, as the distance from land was increased and the area of the land bordering the sea was diminished. It is also possible that the glacial conditions of the lands were simultaneously changed, and less glacial detritus was carried into the sea, at least on the Norwegian side of the basin[1]. If the above theory be correct it seems probable that the surface layer of brown Biloculina clay and transition clay at the bottom of the Norwegian Sea, has been deposited in late glacial and post-glacial times; and as the layer is evidently thin, this might not be altogether improbable, although the brown colour indicate that the deposition has been very slow. But if the changes in the sedimentary conditions be due to oscillations of the shore-line, it is also probable that the grey underlying clay will prove upon closer examination to be stratified, and though it may have a greater thickness than the overlying brown clay, it may possibly rest on brown clay or similar bottom deposits.

It seems very likely that the recent oscillations of shore-line which have probably caused the observed stratification of the bottom deposits of the Barents Sea (the Rhabdammina clay) and at our Station of October 4th, 1893, (the overlying grey clay) may have been too insignificant to make much difference in the deep Norwegian Sea; but the possibility is not excluded that the bottom deposits of the continental declivity or the deep submarine fjords of the Norwegian continental shelf may, upon closer examination, show indications of a similar stratification.

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[1] It might seem possible that mere changes of climate may explain the above stratification of the bottom-deposits of the Norwegian Sea. In this case the grey underlying clay was probably deposited during the glacial periods when much glacial detritus was carried into the sea. It is, however, in my opinion, doubtful whether this could cause such a striking difference in the sedimentary conditions even at the bottom of the great deeps, unless there was some oscillation of the shore-line. The latter explanation seems to me to be more natural.

The Sedimentary Conditions of the North Polar Basin.

Matter originating from organic life. A very conspicuous feature of the bottom deposits of the North Polar Basin is the unusually small amount of matter originating from organic life. By a provisional examination of the bottom-samples it was, in most cases, extremely difficult to find traces of shells of Foraminifera or other organisms. The greatest percentage of carbonate of lime was about 5 % found in the bottom sample of January 23rd, 1895 (83° 24′ N. Lat., 102° 14′ E. Long.). The other samples contained between 1 and 3 % of carbonate of lime.

This scarcity of matter originating from organic life is not surprising according to our present knowledge of the biological conditions of the ice-covered Polar Sea. In Memoir No. 9, pp. 422—423, it was pointed out that the organic life in the North Polar Basin is extremely poor owing to the fact that the greater part of the light is absorbed by the thick ice-layer continually covering the sea. Considering this and the fact that I hardly found any Foraminifera in the Plankton samples taken in the North Polar Basin, it seems even strange that the number of shells of Foraminifera should be as great as was found in the bottom samples from the deep sea; and I consider it therefore probable that these deep-sea deposits must have been formed during a previous period when the biological conditions of the North Polar Basin were more favourable than they are now[1]. This may perhaps also harmonize with the fact mentioned above, that at some places on the bottom of the Norwegian Sea the uppermost layer of the Biloculine clay contained no shells of Foraminifera, which may indicate that the biological conditions of the sea have lately been less favourable than formerly.

Mr. HANS KIÆR has rendered me the great service of identifying the shells of Foraminifera he has been able to find in the bottom samples from the North Polar Basin, and in next Memoir, Appendix II, he gives a list of the species found. Concerning the occurrence of Thalamophora, KIÆR says that the deep-sea clay of the North Polar Basin is very much like the Biloculina clay of the Norwegian Sea, although shells of Biloculina have not been found; but

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[1] The Globigerina shells appear to have been dead for a long time according to Mr. H. KIÆR's description (see Memoir No. 14, Appendix II).

the other Thalamophora appear to be the same as in the Biloculina clay. It seems to me probable that the brown deep-sea clay of the North Polar Basin corresponds to the Biloculina clay of the Norwegian Sea, and that the greater part of both has been deposited during a period when the biological conditions were more favourable for Foraminifera than they are now[1]. Although as a rule, the percentage of carbonate of lime is much greater in the Biloculina clay (15—50 %) than in our bottom samples, this is not always the case. At some deep stations of the Norwegian North Atlantic Expedition in the northern Norwegian Sea, the percentages of carbonate of lime in the bottom samples, approach those found in our bottom samples. I may instance, Stations 245 (4·66 %), 298 (5·52 %), 301 (5·68 %), 352 (7·57 %), which have depths of between 2700 and 3700 m.[2]

Deposition of terrigenous matter. Is has been generally assumed that there is a comparatively rapid deposition of waste in the North Polar sea; enclosed as it is, by continents and receiving as it does the waters from the Siberian and North American rivers which have a very extensive drainage area. Our investigation does not, however, seem to support such an assumption. The deposits covering the greater part of the bottom of the deep North Polar Basin traversed by the Fram, consisted of brown deep-sea clay of an unusually fine grain indicating a slow deposition, as described by Mr. BØGGILD. In the shallow sea nearer to the coast of Siberia, the deposition is naturally more rapid, but even here we found in several places grey, comparatively finely grained deposits with a slightly brownish shade indicating slow deposition. It thus seems as if the rivers do not carry so much solid material into this sea as was generally assumed.

The transportation of terrigenous waste by sea-ice. The fineness of the deposits of the North Polar Basin is very remarkable, as a comparatively large amount of stones and coarse material was generally considered to be

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[1] To what little extent the composition of the bottom deposits of the Ocean is dependent on the present biological conditions of the sea, is also in my opinion demonstrated by the fact that the German Antarctic Expedition commanded by Prof. ERICH VON DRYGALSKI, found that the bottom deposits of the Antarctic Sea contained very little carbonate of lime and shells of diatoms in the region of the Heard Island, although the sea now abounds in diatoms and organisms with calcareous shells. It seems probable that the deposits originate from a former period with different biological conditions.

[2] See L. SCHMELCK, l. c., p. 64.

a characteristic feature of Arctic deposits, especially in regions where the sea is much ice-covered. The evident explanation is that during late geological periods there has been no great drift of glacial ice across the North Polar Basin, and even though a Siberian Ice Age has probably existed, no great amount of land ice can lately have been discharged into the Polar Sea. The absence of coarse material in all our bottom samples from the Siberian Sea and the North Polar Basin also seems to prove that the shore-ice and river-ice can, generally speaking, be of no great importance in the transportation of coarse material. Several authors have even maintained that the shore-ice should have played an important part in the transportation of eratic blocks during the glacial periods and later. I have travelled across a very extensive area of drifting ice on the North Polar Basin, as well as in other parts of the Arctic Sea, but only an some very few occasions I have been fortunate enough to find stones as large as a pea or larger, lying on the floe-ice or imbeded in it. I consider it impossible that, at least in a very cold sea, the transportation of stones or coarse material by shore-ice can be of much significance, especially if compared with that of the glacial ice, for else we should probably have found coarse material at least in some sample from the bottom north of the Siberian coast, or in the North Polar Basin, where so much shore-ice travels across the sea every year.

I have, however, frequently had opportunity of noticing that the coast-ice and the river-ice — *e. g.* from the Siberian rivers — actually transport terrigenous waste. Both in the North Polar Sea itself and in Denmark Straits I have often found comparatively great quantities of mud and dust on the ice-floes.[1] But this transportation of waste is of little importance in the formation of bottom deposits in the North Polar Basin, as the shore-ice melt there only to at very small extent and only near the coasts during the first summer, whilst by far the greater part is carried across the North Polar Basin, growing in thickness on the way, and is finally melted in the sea east of Greenland and farther south, where the terrigenous matter is

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[1] 'Wissenschaftliche Ergebnisse von Dr. F. NANSENS Durchquerung von Grönland', *Petermanns Mitteil.*, Ergänzungsheft No. 105, 1892, pp. 101—108.

During the sledge journey in 1895, of JOHANSEN and myself, we often even farthest north, observed ice which was quite dark with imbeded mud, so much so that seen in a distance the ice-blocks in the hummocks might look like rocks.

then deposited. As, even during the summer, the ice-floes melt extremely little on their under side, it is merely accidental that the terrigenous waste lying on their surface or imbeded in them can get an opportunity of sinking to the bottom of the North Polar Basin. By the melting on the ice-surface, every summer, the mud may accumulate to form layers, and some small part of it may also occasionally be carried into the lanes between the floes, by the fresh melting-water. During ice-pressures, when an ice-floe is crushed or turned upside down, some small amount of mud may also get an opportunity of sinking; but this will be of little significance.

There is also another circumstance which may diminish the deposition of sediment in the North Polar Sea. The dust carried by the winds as well as the dust of the atmosphere carried down by the precipitation is there by the floating ice prevented from being deposited on the sea-bottom. By the surface-melting of the ice every summer this dust is accumulated on the ice surface to give the latter a brownish dirty appearance, and it is carried along to be deposited in more southern latitudes, where the ice melts.

From what has been said above it seems probable that the deposition of sediments on the bottom of the North Polar Basin must be comparatively small, and that the sediments formed must be of a comparatively fine grain; especially if compared with regions of the northern seas where floating glacial ice generally occurs.

XII. THE POSSIBLE FORM OF THE NORTH POLAR BASIN.

Form of the Basin. In Memoir No. 9 ("The Oceanography of the N. P. Basin", p. 406) it is pointed out that the distinct difference, in salinity and temperature as well as in density, between the bottom-waters of the North Polar Basin and of the Norwegian Sea, proves that these two basins must be separated from each other by suboceanic ridges, just as the Norwegian Sea is separated from the Atlantic by the Wyville Thomson Ridge and the Færoe-Iceland-Greenland Ridge; the ridge between Spitsbergen and Greenland may, however, probably stand somewhat lower than the above ridge, at least at some places.

The fairly numerous soundings in the sea between Novaya Zemlya and the Franz Josef Archipelago show that a comparatively high submarine plateau extends between these two lands (see Pls. I and II). This plateau is traversed by submarine valleys runing in different directions (cf. above p. 30), and the highest ridge, which would form the water-shed if the plateau were lifted above sea-level, has therefore probably a very winding course. It seems to run from the NW-coast of Novaya Zemlya in about 76° N. Lat. (see Pl. II) westwards to a point in about 76° N. Lat. and 45° E. Long.; thence northward to unite with a ridge that probably unites Spitsbergen and King Charles Land with a ridge extending southward from Franz Josef Land (see Pl. I). The greater part of these ridges is less than 200 m. deep (between 100 and 200 m.), and the deepest pass is possibly in about 76° N. Lat. and 47° E. Long., where there are soundings of 220 and 229 m. If this be correct *the North Polar Basin is, in this region, separated from the Barents Sea and the Norwegian Sea by a continuous submarine ridge, less than 220 m. deep,*

extending from Novaya Zemlya to Franz Josef Land and to Spitsbergen. From a point in about 76° N. Lat. and 45° E. Long., on this ridge, a narrow submarine valley, probably more than 300 m. deep[1], passes NE-wards and evidently comunicates with a deep embayment of the North Polar Basin, extending southward, east of Franz Josef Land (cf. Pl. I, and above p. 16). How broad this embayment is, cannot be determined by the few soundings hitherto taken, the deepest of which are 515 m.[2] To the north of the Novaya Zemlya Spitsbergen Ridge there are evidently also submarine valleys and fjords communicating with a deep fjord or embayment, with depths of 421 and 512 m. (see above p. 16)[2], extending from the North Polar Basin southwards between Spitsbergen and the Franz Josef Archipelago (see Pl. I).

According to the soundings hitherto taken, a suboceanic ridge is evidently extending towards NW from the north-western corner of Spitsbergen. From the highest part of this ridge only three soundings are known, *viz.* 476 m. in 80° 3′ N. Lat. and 8° 28′ E. Long.; 839 m. in 79° 59′ N. Lat. and 5° 40′ E. Long.; 786 m. in about 81° 2′ N. Lat. and about 3° 50′ E. Long.[3] These soundings, the two former of which were taken during the Norwegian North Atlantic Expedition in Aug. 1878, are far apart, and it is uncertain whether they happened to hit the highest part of the ridge. To judge from the oceanographical features of the North Polar Basin it seems, however, probable that the ridge is not very much higher in this region, because the Gulf Stream water, running into the North Polar Basin, and approximately determined by the isotherms of 0·5° C. and 0° C., has in the region to the NE, evidently a depth of 700 or 800 m. (see Memoir No. 9, Pls. XIV, XV, XXXII, and p. 334). Farther west, the Spitsbergen-Greenland Ridge is probably higher, to judge from the oceanographical features both of the North Polar Basin and of the sea off the Greenland east coast (see Memoir No. 9, pp. 410 and 413); but nothing can be said as to the shape and extension of the ridge.

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[1] This submarine valley is seen on Pl. II, but one sounding by Mr. Bruce of 385 m., and two soundings by the Duke of Abruzzi, of 336 and 320 m. (see Pl. I), obtained after Pl. II was printed, make it probable that the valley has a continuous depression of more than 300 m.

[2] Although it may be quite accidental, it is worthy of note that even at these two places we find a coincidence of soundings of about 500 m., as near the mouth of the submarine fjords of the Barents Sea and farther south (see p. 208).

[3] See H. Mohn, 'The North Ocean', *Norw. N. Atlantic Exp.*, Pl. I.

We thus see, that we probably have to distinguish between three different depressions, which are not continuous; *viz.* the eastern basin of the North Atlantic, the Norwegian Basin, and the North Polar Basin. It has been assumed that these basins "belong to one and the same great geosynclinal depression"[1], but this is not certain. The continental slope forming the eastern margin of the basins, has, on the average, a fairly meridional direction from north-western Africa to the north of Ireland; but west of Scotland it trends in a more north-easterly direction towards northern Norway, and then west of north, towards the north-western corner of Spitsbergen; at this point the slope suddenly turns eastward at a right angle. Thus the trend of the eastern margin, also seems to distinguish the basins as three different depressions.

Our assumptions as to the width and extension of the deep North Polar Basin must necessarily be extremely uncertain and hypothetical, as long as we have no soundings in the vast region on the Greenland-American side, between Spitsbergen and the coast of Alaska. The oceanographical features observed during our expedition, indicate, however, that the deep Basin must have a much wider extension than observed by us; the Fram cannot have drifted along a deep and narrow suboceanic channel, extending merely from the sea north of Siberia towards the Spitsbergen-Greenland Ridge. I may especially mention that the existence of the cold bottom-water of the North Polar Basin makes such an assumption perfectly impossible. This heavy bottom-water which, at depths greater than 800 or 900 m., has temperatures between 0° and —0·9° C., originates from the inflowing Atlantic water, but it cannot have been cooled down to its low temperature at the depths where it was observed by us, for the overlying water is warmer, and underneath it is the sea-bottom which at that depth must, on account of the subterranean heat (see Memoir No. 9, pp. 337—346) have a higher temperature than the water. The cold bottom-water to have been cooled down to nearly —0·9° C., must somewhere in the still unknown portion of the North Polar Basin have been in contact with the surface-layer of cold polar water with a temperature below —1° C.[2], and this cannot have occurred anywhere near

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[1] HUDLESTON, *Geol. Mag.* Dec. IV, vol. VI, 1899.

[2] This surface-layer was along the Fram's track about 160 m. thick, see Memoir No. 9, Pl. XV.

the Fram's track, as is proved by the oceanographical conditions observed, but must have been somewhere far off, probably towards the north or north east (cf. Memoir No. 9, pp. 399 *et seq.*). In Memoir No. 9, p. 416, I have pointed out that (according to Capt. ROALD AMUNDSEN's observations) the cold bottom-water of the Norwegian Sea is formed by cooling at the surface in the region north of Jan Mayen, between Lat. 73° and 75° N. and Long. 1° and 10° W., where the Norwegian Sea has, so to speak, its dynamic centre. In a similar manner the North Polar Basin must, according to my view, have its dynamic centre somewhere, perhaps in the region between the North Pole and Bering Straits, where the layer of cold bottom-water approaches the surface[1]; a difference being, however, that the bottom-water does not actually reach the surface, but is only cooled down by contact with the cold surface layer of less saline polar water (see Memoir No. 9, Pl. XXIX); the result is that this bottom-water is protected from being cooled down to the low temperature of that of the northern Norwegian Sea.

From what has been said above it may be concluded that to explain the observed oceanographical features (temperatures and salinities) of the North Polar Basin, we are obliged to assume that it has a wide extension, and I feel inclined to believe that the deep basin covers the greater part of the still unknown north polar region.

The continental slope at the edge of the continental shelf, bounding the deep Basin is only known at two places: north of Kotelnoi and north of Spitsbergen. In the former place the slope begins about 240 kilometres from the nearest land (Kotelnoi) but is very steep, about 1 in 18 or 3° 15′ (see p. 20). North of Spitsbergen the continental slope is only about 50 kilometres from land or less, but is very gentle, about 1 in 36, or 1° 36′.

How far the continental shelf extends north of the Franz Josef Archipel- it is impossible to say, but its edge has at any rate probably been far south of the Fram's route. At a point where the continental shelf extends far north, the warm under-current will also be forced northward, and the warm under-current would at such a place of the Fram's route, show higher temperatures than elsewhere; there is, however, hardly any indication of such differences,

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[1] This is simply a consequence of the tendency of the moving water to attain a state of lateral equilibrium, see Memoir No. 9, pp. 398 and 402—404.

except such as might be explained by the more or less northern position of the stations (see Memoir No. 9, p. 334). It was above (p. 226) pointed out, that east of the Franz Josef Archipelago there is probably a deep southward embayment of the deep North Polar Basin; it seems possible that the temperatures of Stations 20 and 19, (see Memoir No. 9, Pls. I and XV) might indicate the existence of such an embayment, as the temperatures of the former station were slightly lower than those of the latter. Near the coast just off Cape Chelyuskin and farther east, the depths found by the Vega Expedition were comparatively great, between 80 and 120 m., but it seems very doubtful whether this indicates a narrower continental shelf. The deep-sea temperatures along the Fram's track tell us very little in this respect, except that Stat. 14 (in about 80° 20′ N. Lat., 132° E. Long.) was probably situated nearer the continental slope than the stations farther west.

It was mentioned above that the Jeanette possibly for some time drifted near the margin of the continental shelf (see above p. 15); but even if we assume that the sounding of 156 m. — in 75° 50′ N. Lat. and 169° 56′ E. Long. (see Pl. I) — was on the very edge, which does not seem improbable, the continental shelf would in this region have a width of about 640 kilometres. North of Wrangel Island and Bering Straits, the most northern soundings known seem to have been near the edge of the shelf, and they indicate some irregularities in the contours which may be drowned valleys (see Pl. I). In this region the shelf is at least 600 kilometres broad; but farther east, north of Alaska, the soundings indicate that it becomes very narrow (70 kilometres, see above p. 23), and is probably bounded by a fairly steep continental slope. This is in good harmony with our observations from other regions; for Alaska is a comparatively high land with high coasts (see Pl. I), which have offered comparatively great resistance to marine denudation; in addition, the water-shed of the land is near the north coast, and the greater part of the waste has obviously been carried by the great Yukon River and other rivers into the Bering Sea, where there is a broad continental shelf.

It is, I believe, probable that there is a deep sea north of Alaska, not far beyond the northernmost soundings, and that this deep sea is a part of the deep basin crossed by the Fram, which extends right across the unknown region.

How far the continental shelf extends north of the American Arctic Archipelago and Greenland is unknown, but as northern Greenland, Grinnell Land, and Axel Heiberg Land (discovered by SVERDRUP), are comparatively high lands it might seem probable that the continental shelf to the north is at least not so broad as it is on the Siberian side of the basin. The Amund Ringnes and Ellef Ringnes Lands, as well as the Prince Patrick and Melville Islands, are lower and there may be a possibility of more extensive drowned plains to the north of them.

It is impossible to say whether we now actually know the northernmost lands. I do not deny the possibility of unknown lands still existing to the north, but according to what has been said above, about the probable size of the North Polar Basin, I do not believe that such lands, if they exist, can have a very great extension, nor do I think that any great lands can anywhere have been near, to the north of the Fram's route; this may according to my view be inferred not only from the oceanographical observations, made during the expedition (see above), but also from the broad southward drift of ice along the east coast of Greenland. As I have pointed out elsewhere[1], the Fram would certainly not have drifted southwards close under the east coast of Greenland, if she had continued her drift with the ice in the summer of 1896, instead of working her way towards Spitsbergen. She would undoubtedly have had a broad belt of ice between her and the Greenland coast; and as the ice drifts with a much greater speed in this region, than farther north in the North Polar Basin, the belt of ice east of Greenland must consequently correspond to a very much broader belt in the known and unknown polar sea, from which the ice converges. In 1897 I said that I consequently thought we might conclude that on this side of the pole there is an extensive ice-covered sea, while in the American Arctic Archipelago we might "expect to find islands, perhaps islands of some magnitude, north of the limit which has been reached". This expectation has now been fulfilled by the discoveries of SVERDRUP during the second Fram expedition; but whether there may exist lands still farther north it is difficult to say; we do not even know whether the sea is deep or shallow, north of these northern coasts.

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[1] *Geograph. Journal*, London, vol. IX, 1897, p. 480.

Postscript. I have forgotten above, to mention the possibility that the drowned valleys may, at least in some cases, have been deflected down to their present deep levels by the sinking of the oceanic bottom. *E. g.* the great depths to which the submerged channels of the *Congo*, the *Adour*, etc., descend, might possibly be thus explained; but where the submerged river valleys cut deep and narrow channels across a broad and nearly horizontal continental shelf, *e. g.* the submerged valleys of the *Hudson* River, the *St. Lawrence*, etc., an explanation such as this would not, at any rate, be tenable.

ADDITIONS AND CORRECTIONS.

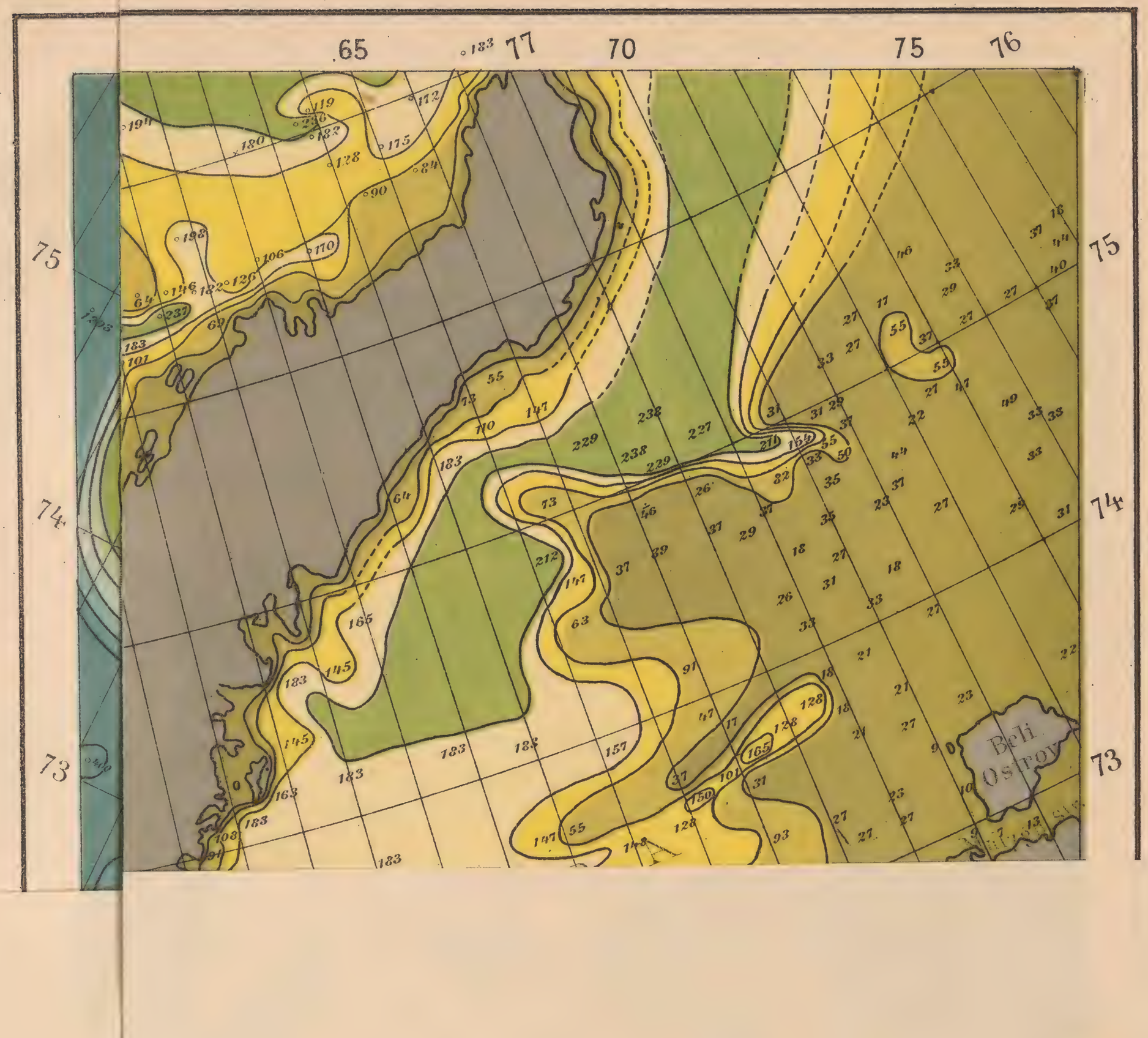
Page 28, line 11 and 12, cf. p. 163 footnote 1.
„ 31, line 15, *for* 400 m. *read* 400 and 460 m.
„ 31, line 16, *for* 200 m. *read* 424 m.
„ 48, 4 lines from foot, *for* 533 *read* 514.
„ 49, Table, 2nd column, first line, *for* 533 *read* 459.
„ 49, Footnote 1, line 3, *for* 533 m. *read* 459 m. The sounding of 283 Norwegian fathoms (= 533 m.) in Generalkart B 14 (1902), of *Norges Geografiske Opmaaling*, is a misprint for 233 Norwegian fathoms (= 439 m.). The deepest soundings are 459 m. and 456 m. (244 and 242 Norw. fathoms). See also 'Fiskekart over Varangerfjorden', published by *Norges Geografiske Opmaaling*.
„ 58, line 19, *for* trough *read* through.
„ 210, line 6, *for* Iceland *read* Ireland.

Depths and Heights, in all Plates, are given in Metres.

Additions to Pl. II.

The following soundings should be added:

N. Lat.	E. Long.	Depth in Metres	Source
72° 22′	19° 10′	494	'Nördliches Eismeer Barents See', Chart No. 155, published by *Reichs Marine Amt, Nautischer Abtheilung*, Berlin, 1901.
72 36	19 10	457	
72 29	20 40	460	
73 22	20 10	535	
73 10	21 11	548	
72 21	27 12	320	
75 32	23 54	366	
76 27	22 20	210	
On the platform round *Bear Island*, and between this island and *Hope Island*, there are noumerous soundings in the German chart, which to some extent alter the shape of the isobaths of 50–200 m., and indicate many submarine valleys.			
73° 52′	41° 18′	262	'The North Cape to Einsamkeit Island including the Barents and Kara Seas', *Admiralty* chart No. 2962, London, 1897.
75 33	42 43	421	
74 1	43 55	366	
73 54	46 12	347	
72 1	38 40	293	
70 42	34 20	121	
70 38	33 40	258	
71 55	41 50	128	
71 52	43 20	274	
71 49	44 23	155	
71 34	43 46	155	
72 56	46 26	60	
72 54	46 45	113	
73 4	46 42	73	
72 58	46 58	137	
73 10	47 24	139	
74 56	46 20	274	
74 47	48 13	234	
68° 12′	39° 51′	115	'Osservazioni Scientifiche eseguite durante la Spedizione Polare di S. A. R. Luigi Amadeo di Savoia Duca Degli Abruzzi, 1899–1900', Milano, 1903, p. 180.
71 39	48 53	128	
73 33	50 22	260	
74 16	50 40	245	
75 17	51 0	215	
76 48	52 0	336	
77 21	52 20	320	
77 50	52 40	280	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Beli Ostrov

Bathymetrical Chart
of the
BARENTS AND KARA SEAS.
1901
By Fridtjof Nansen.

Compiled from latest Sources, including soundings of the Fram, 1893; the Nayezhdnik, 1893; Lieut. Zhdanko, 1894-95; Dr. Knipowitch, 1898-1901; Prof. Nathorst, 1898; the Heimdal, 1900; Capt. Roald Amundsen, 1901; Admiral Makaroff, 1901; the Norwegian Coast Survey, etc.

Isobaths drawn for Intervals of 50 Metres.

167 Soundings in Metres.

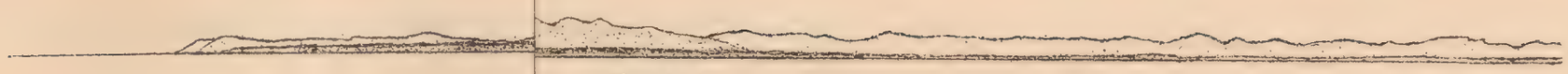
Land
Sea Level
50 Metres
100 "
150 "
200 "
250 "
300 "
350 "
400 "
450 "
Below 450 m.

Scale 1 : 4000000

0 10 20 30 40 50 60 120 Nautical Miles.

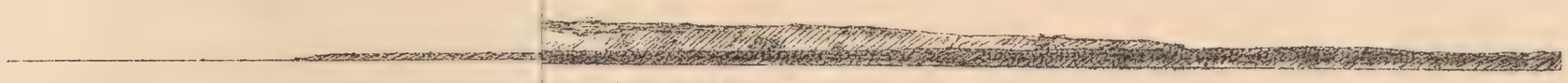
0 20 40 60 80 100 200 300 Kilometres.

Kart-og Litograferingskontoret, Chr.ania.



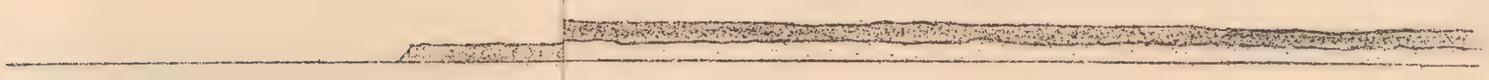
Sept. 12, 1893.

h, Sept. 11, 1893.

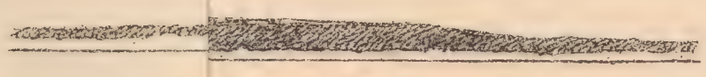


Sept. 9, 1893.

Sept. 9, 1893.



a Photograph.



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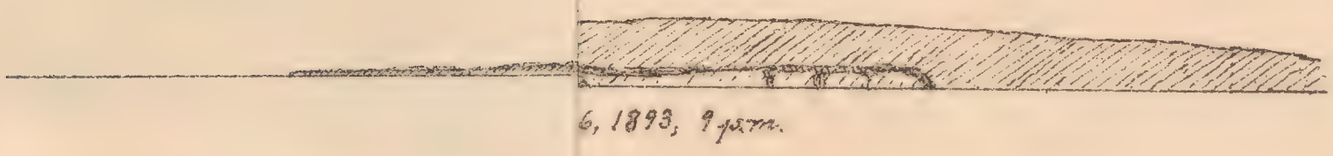
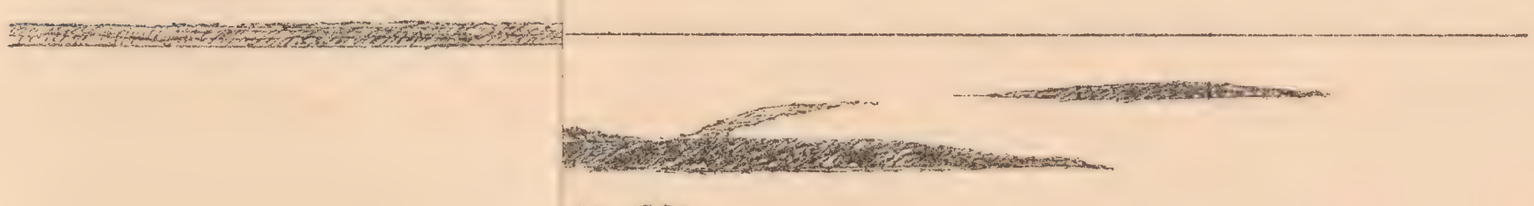


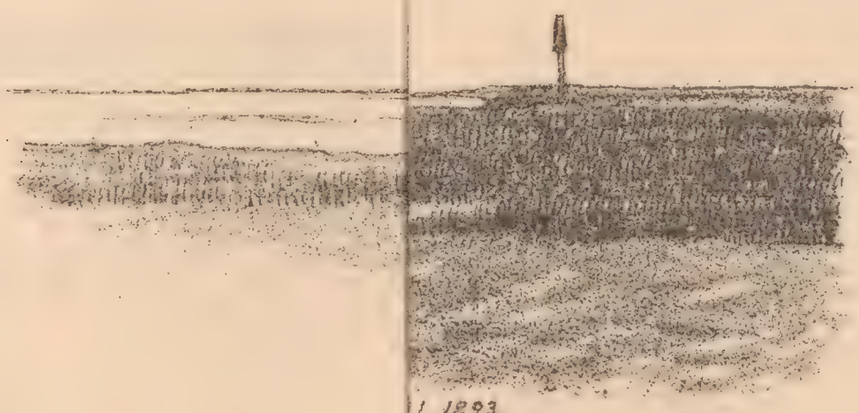
6, 1893, 9 p.m.



20, 1893.

eturned View Photograph May 26, 1893.

93.



1, 1893.

Fig. 1. Coast of Eastern Taimur Peninsula. From a Photograph taken Sept. 12, 1893.

Fig. 2. Northern Coast of Taimur Peninsula. Sketch, Sept. 11, 1893.

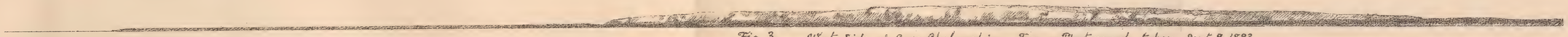


Fig. 3. West Side of Cape Chelyuskin. From a Photograph taken Sept. 9, 1893.

Fig. 4. Cape Chelyuskin. From a Photograph taken Sept. 9, 1893.

Fig. 5. Land near Taimur Sound, seen Aug. 27, 1893. From a Photograph.

Fig. 6. Land near Taimur Sound, seen Aug. 27, 1893, 7 p.m. From a Photograph.

Fig. 7. Fillo Islands. Sketch, Aug. 26, 1893, 9 p.m.

Fig. 8. Hjellman Islands. Sketch, Aug. 20, 1893.

Fig. 9. Northwest coast of Renö (Hjellman Islands). Photograph, Aug. 20, 1893

Fig. 10. West Coast of Renö (Hjellman Islands). Southward View Photograph Aug. 26, 1893.

Fig. 11. Kamenni (Rocky) Island, seen from NNW (magn.) From Photographs and Sketch, taken Aug. 19, 1893.

Fig. 12. Estuary at Khaburova, Yugor Strait to the left. From Photographs, taken July 31, 1893.

Fig. 1. West Coast of Renö, Southward View. From a Photograph, taken Aug. 21, 1893. (74°46' N. Lat.)

Fig. 2. North-western Corner of Chelyuskin Peninsula.
(77°20' N. Lat.) Photograph, Sept. 10, 1893.

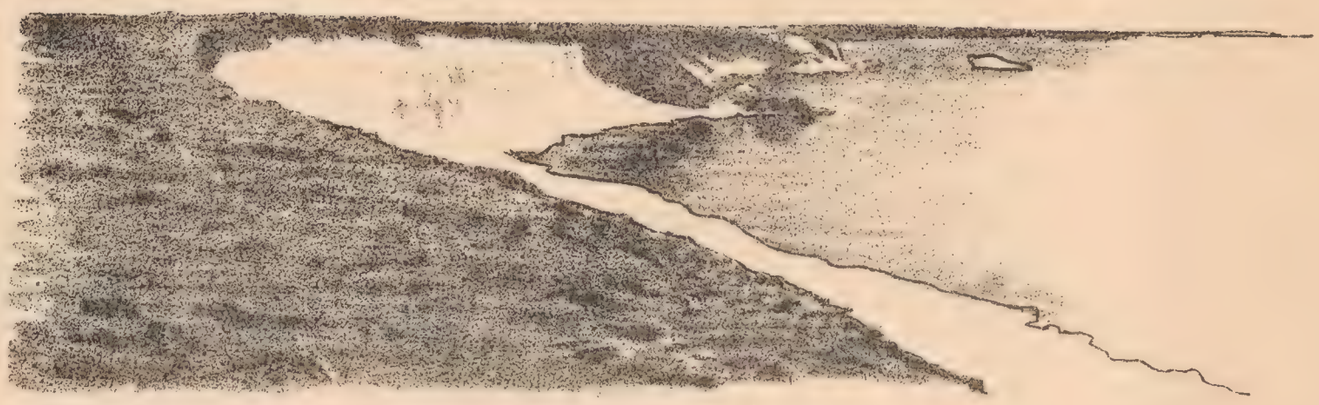


Fig. 4. Cape Cherni, Novaya Zemlya. Photo. by W. S. Bruce.
(70°5.0' N. Lat., 53°26' E. Lat.)

Fig. 3. West Coast of Yalmal. After Photographs taken Aug. 7, 1893. (69°37' N. Lat.).

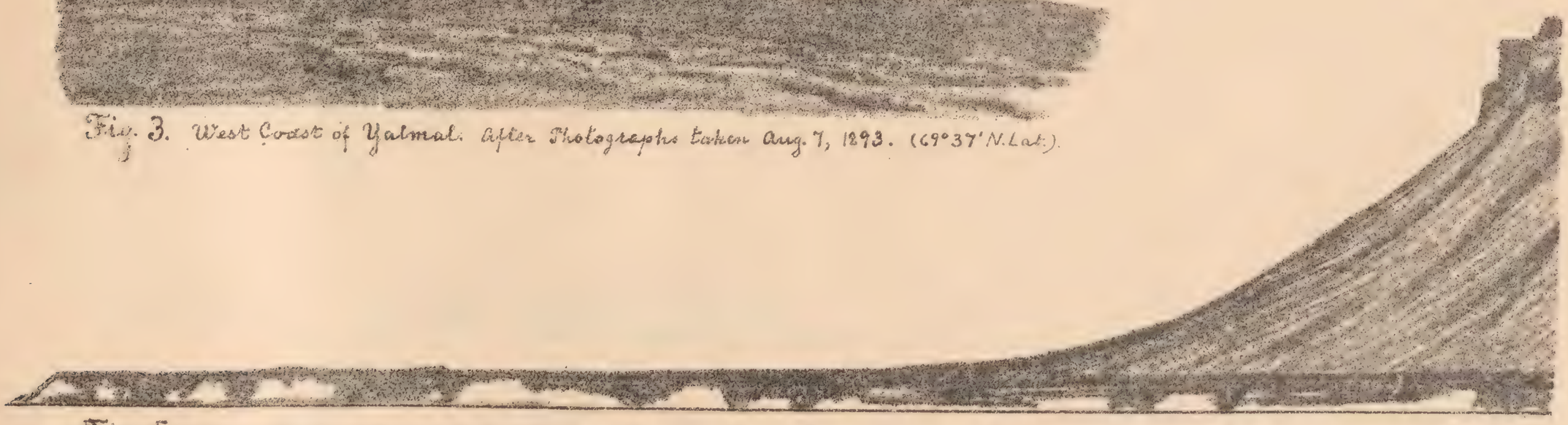
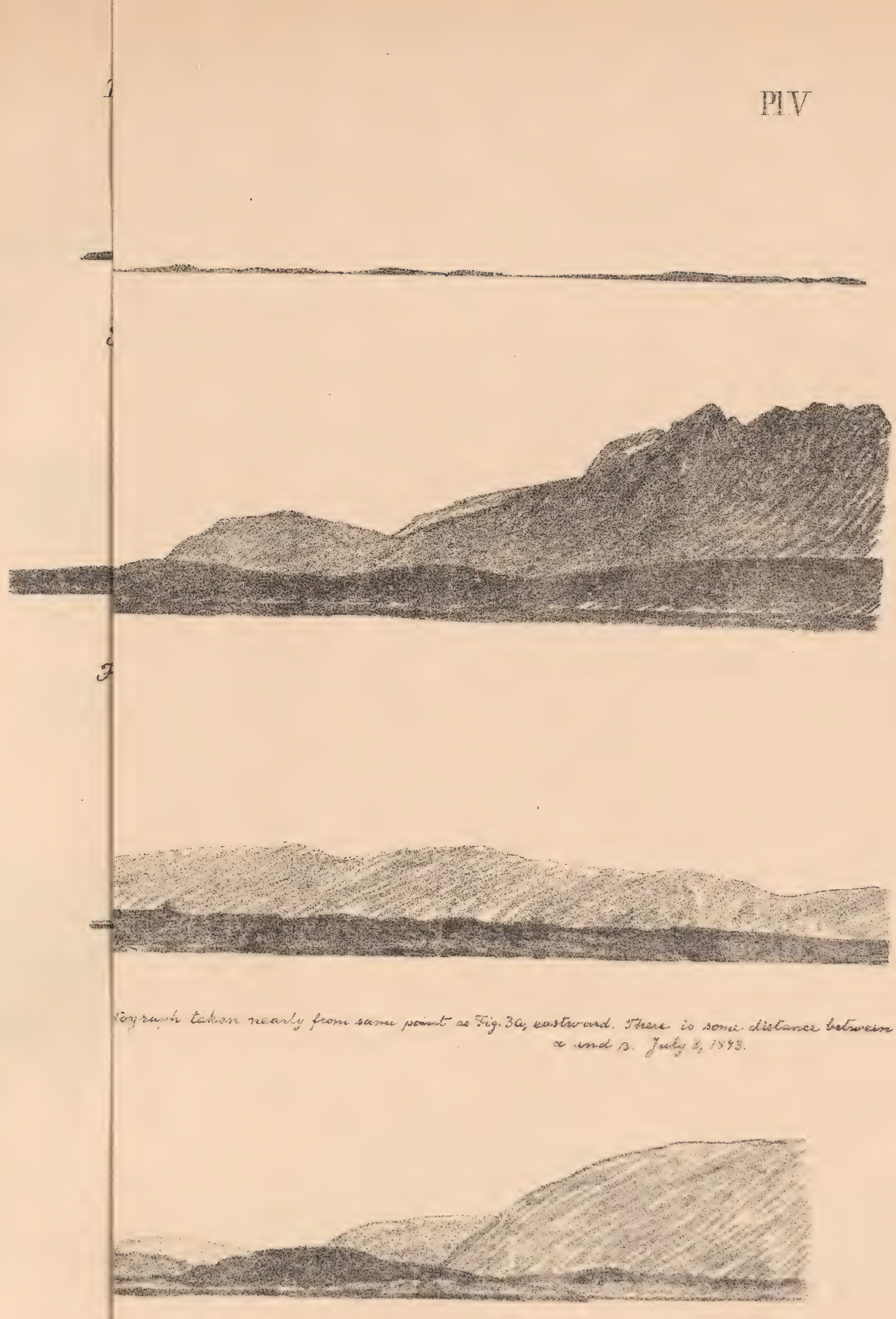


Fig. 5. Cape Flora, Franz Josef Land. Diagrammatic Sketch from Photographs. (69°57' N. Lat.)

Fridtj. Nansen.



Photograph taken nearly from same point as Fig. 3a, eastward. There is some distance between a and b. July 2, 1893.

Fig. 1. Lommen. Photograph, July 9, 1893. (66° 22′ N. Lat.)

Fig. 2. Dönnes ö, west of Syv-Söstre. Sketch, July 8, 1893. (66° N. Lat.)

Fig. 3a. Brönö Sund. Northward view. From Photographs taken July 8, 1893. (65° 28′ N. Lat.)

Fig. 3b. Brönö Sund. Photograph taken nearly from same point as Fig. 3a, eastward. There is some distance between α and β. July 4, 1893.

Fig. 4. Torghatten. Photograph, July 8, 1893. (65° 23′ N. Lat.)

Fig. 5. Horberget and Gulefjeld, Hustadviken, near mouth of Romsdal Fjord. Sketch, July 4, 1893. (62° 57′ N. Lat.)

Fridtjof Nansen.

Fig. 1. Alden, west coast of Norway. Sketch, July 2, 1893. (61°19' N. Lat.)

Fig. 2. Holstensborg, Greenland. Sketch by A. Kornerup, 1879 (66° 56' N. Lat.)

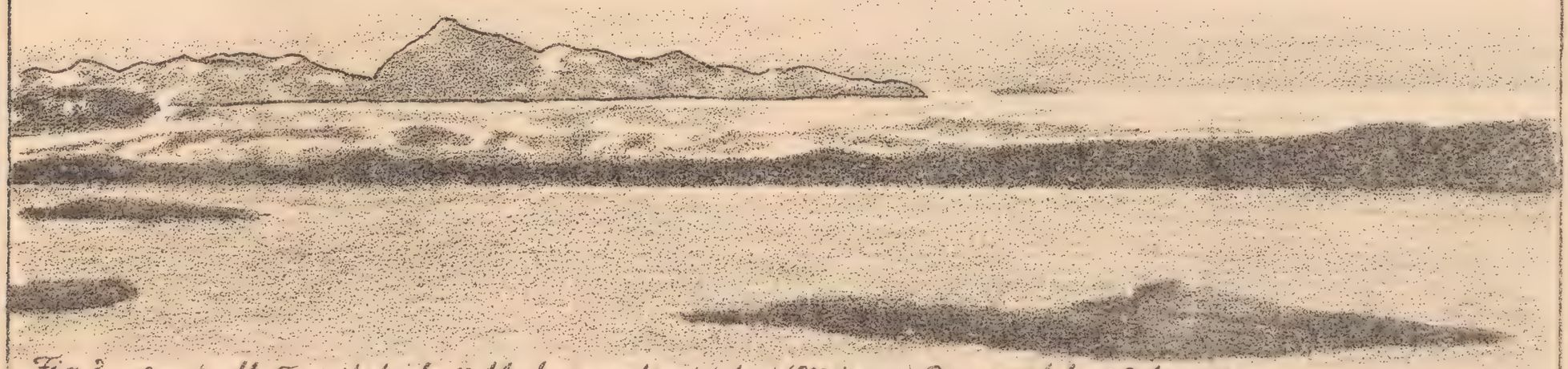


Fig. 3. Coast off Fredrikshaab Isblink, Greenland (about 62°30' N. Lat.) Photograph by C. Ryberg, 1889.

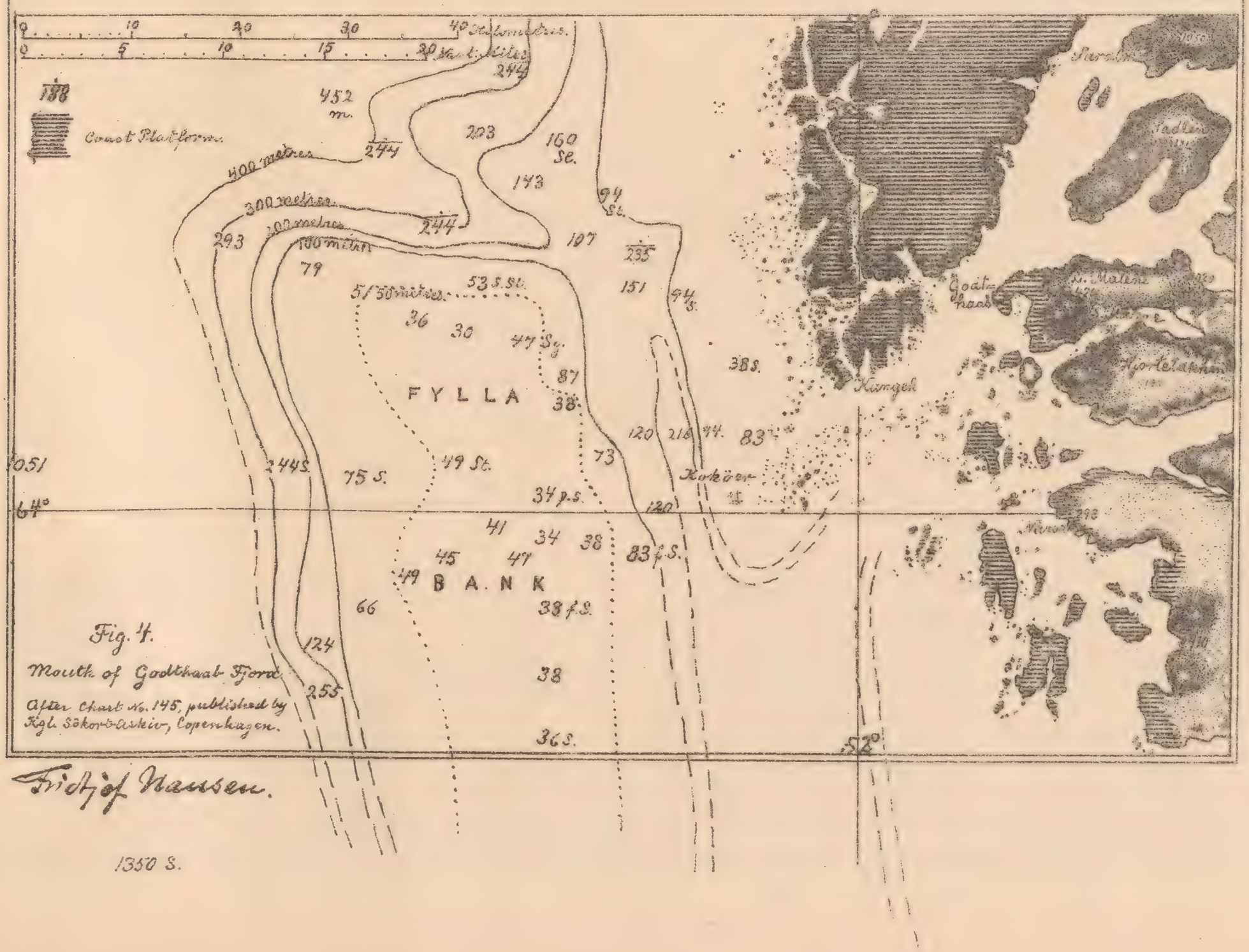
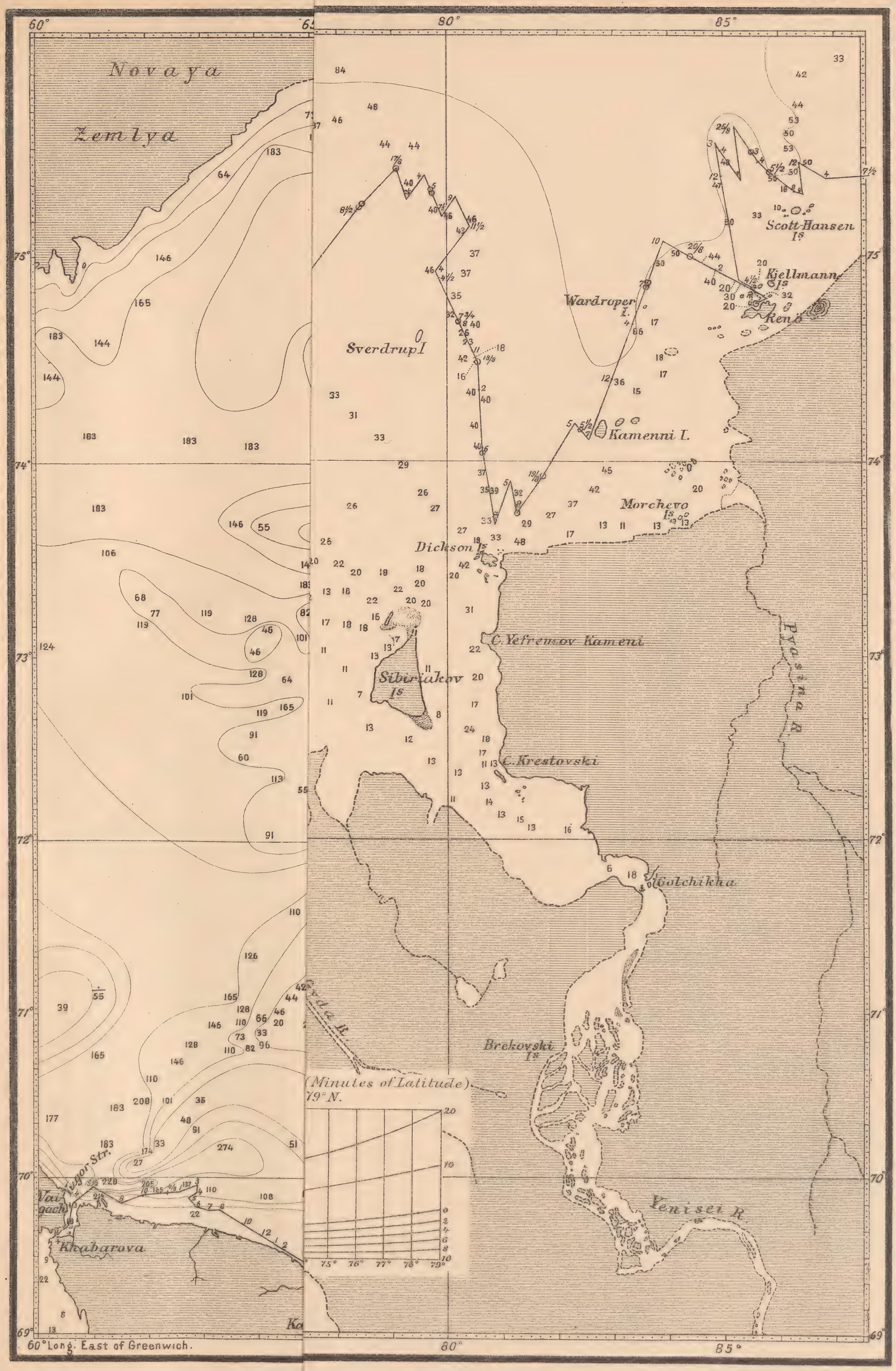


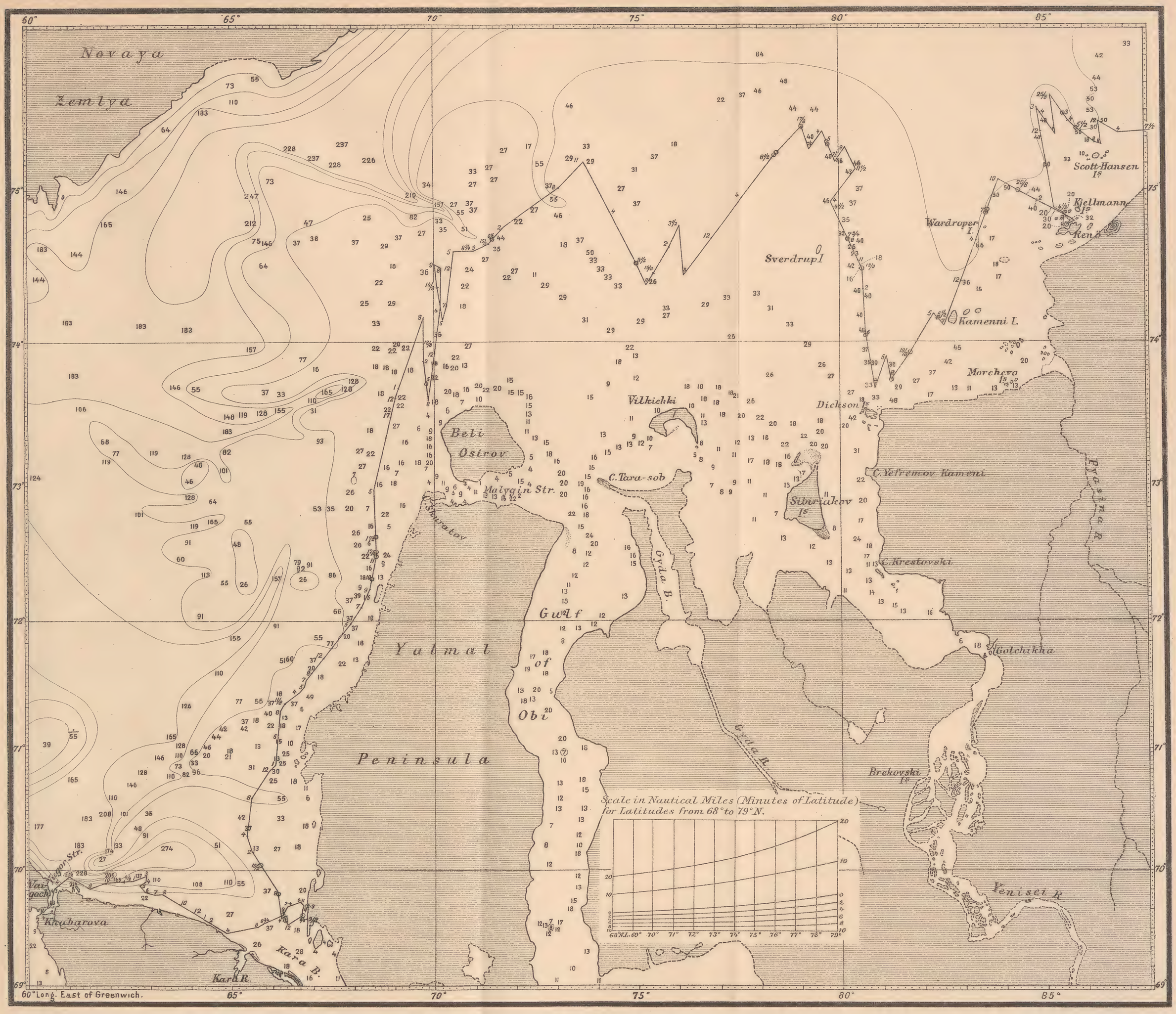
Fig. 4.
Mouth of Godthaab-Fjord.
After Chart No. 145, published by Kgl. Sökort-Arkiv, Copenhagen.

Fridtjof Nansen.



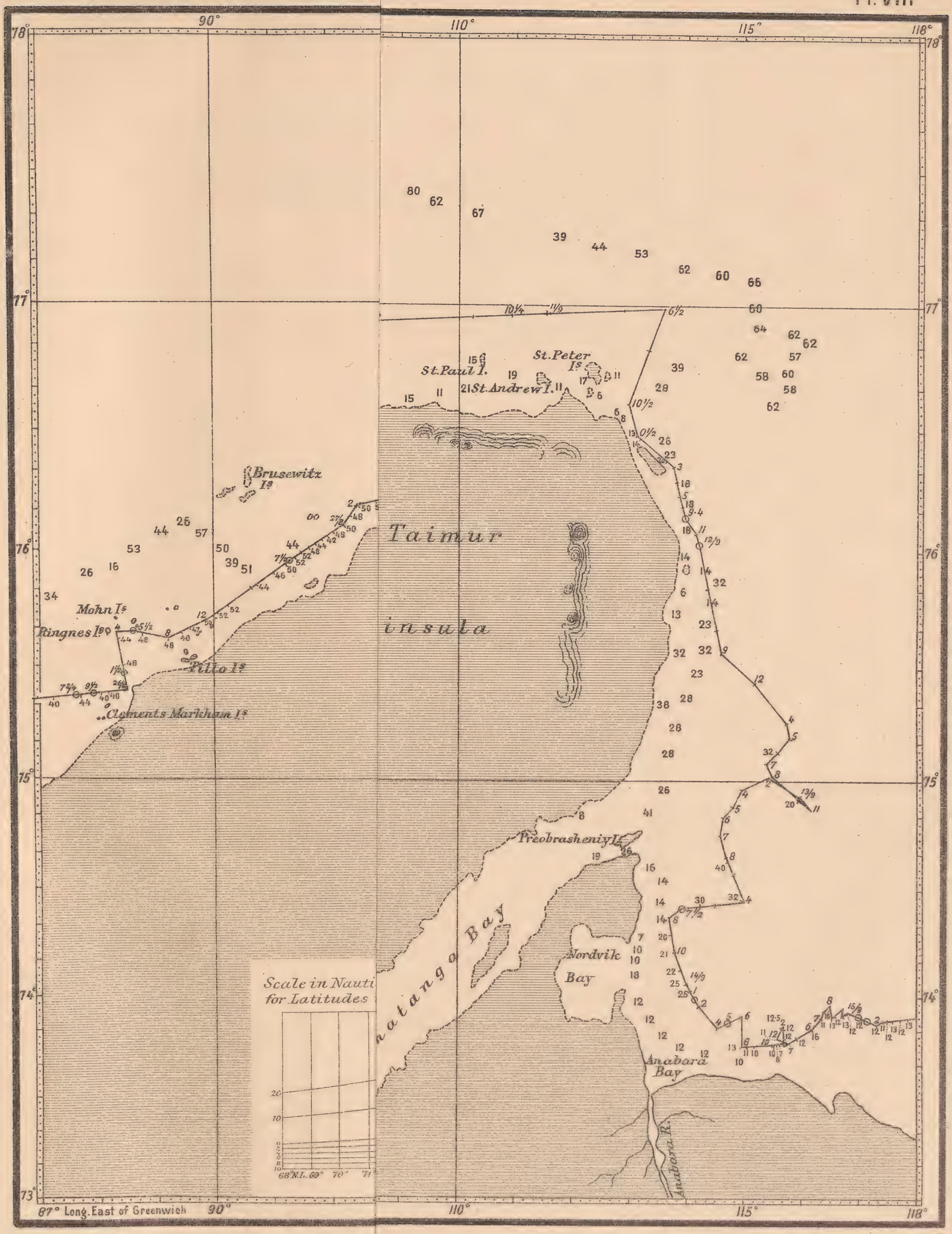
TRAC

Figure, indicate the Depth in Metres.
Figure te (10/8) for every noon and the Hour (8).
The Frobservation, is indicated by a ring thus, ——o——



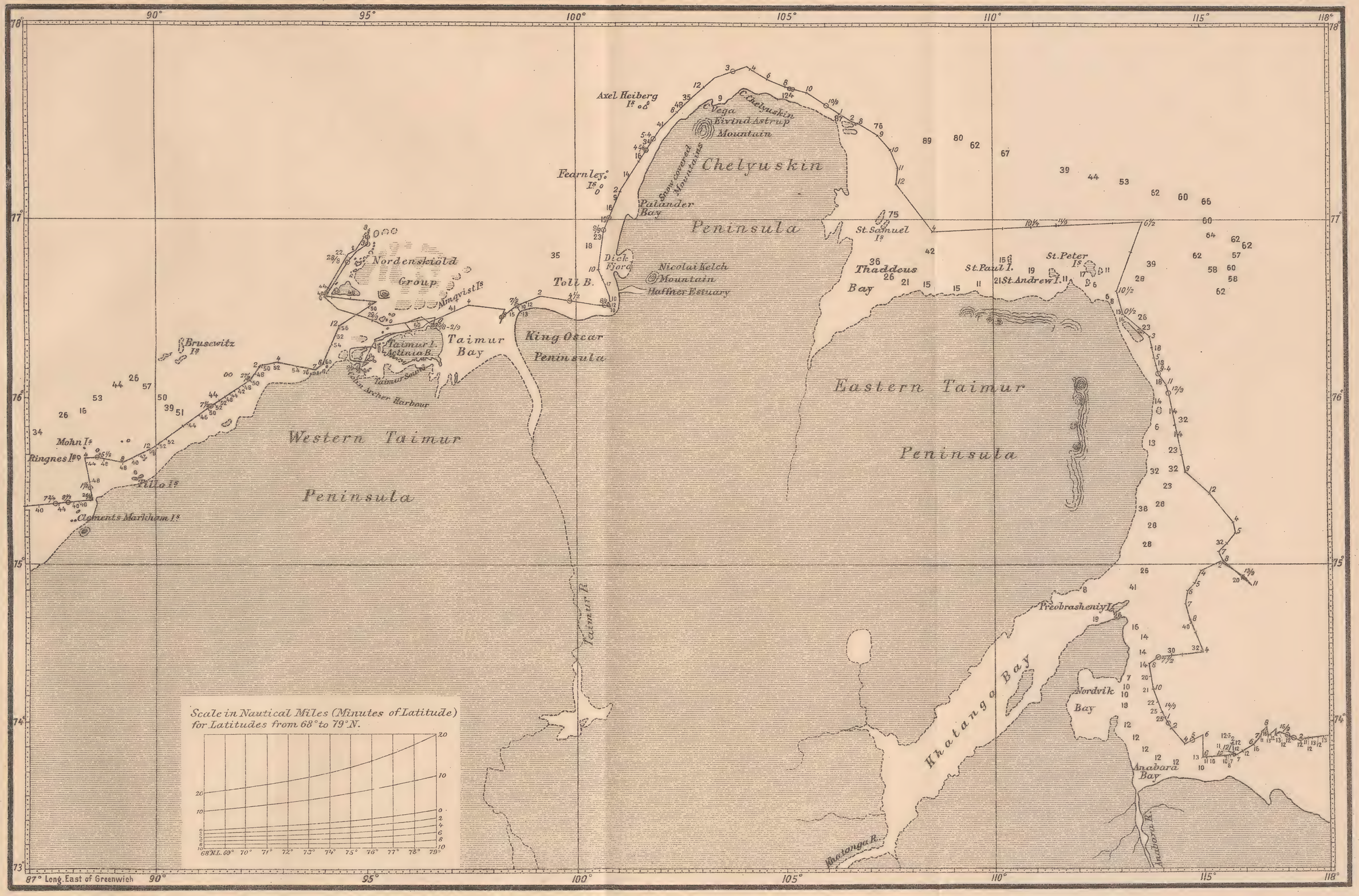
TRACK OF THE FRAM FROM AUGUST 4 (4/8) TO AUGUST 26 7.30 A.M., 1893.

Figures in erect letters thus, 52, along the starbord side of the Fram's track and elsewhere, indicate the Depth in Metres.
Figures in italics thus, 10/8 and 8, along the port side of the Fram's track, indicate the Date (10/8) for every noon and the Hour (8).
The Fram's Track in open water shown thus, ——✗—— Position determined by astronomical observation, is indicated by a ring thus, ——o——



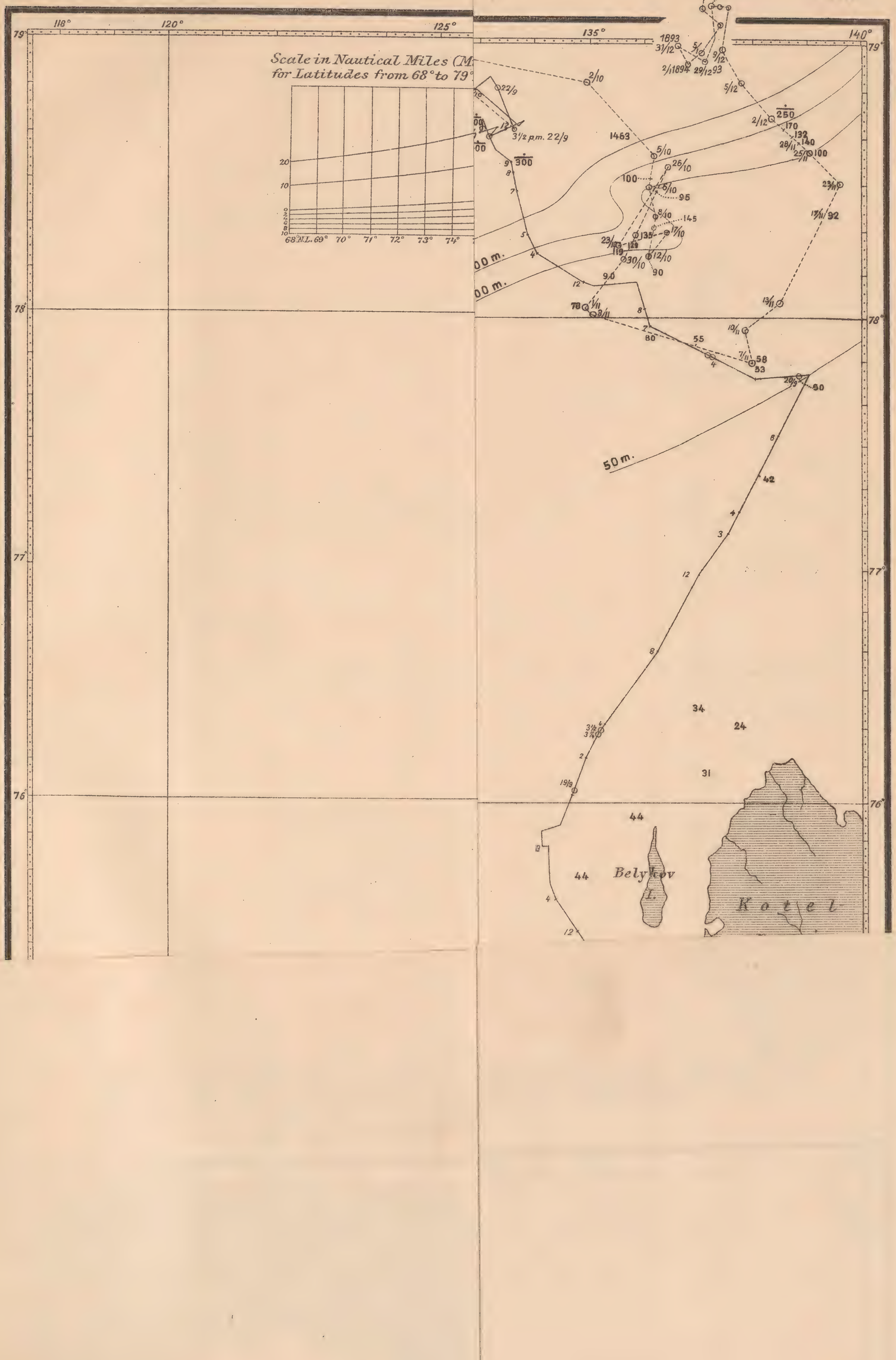
TRA

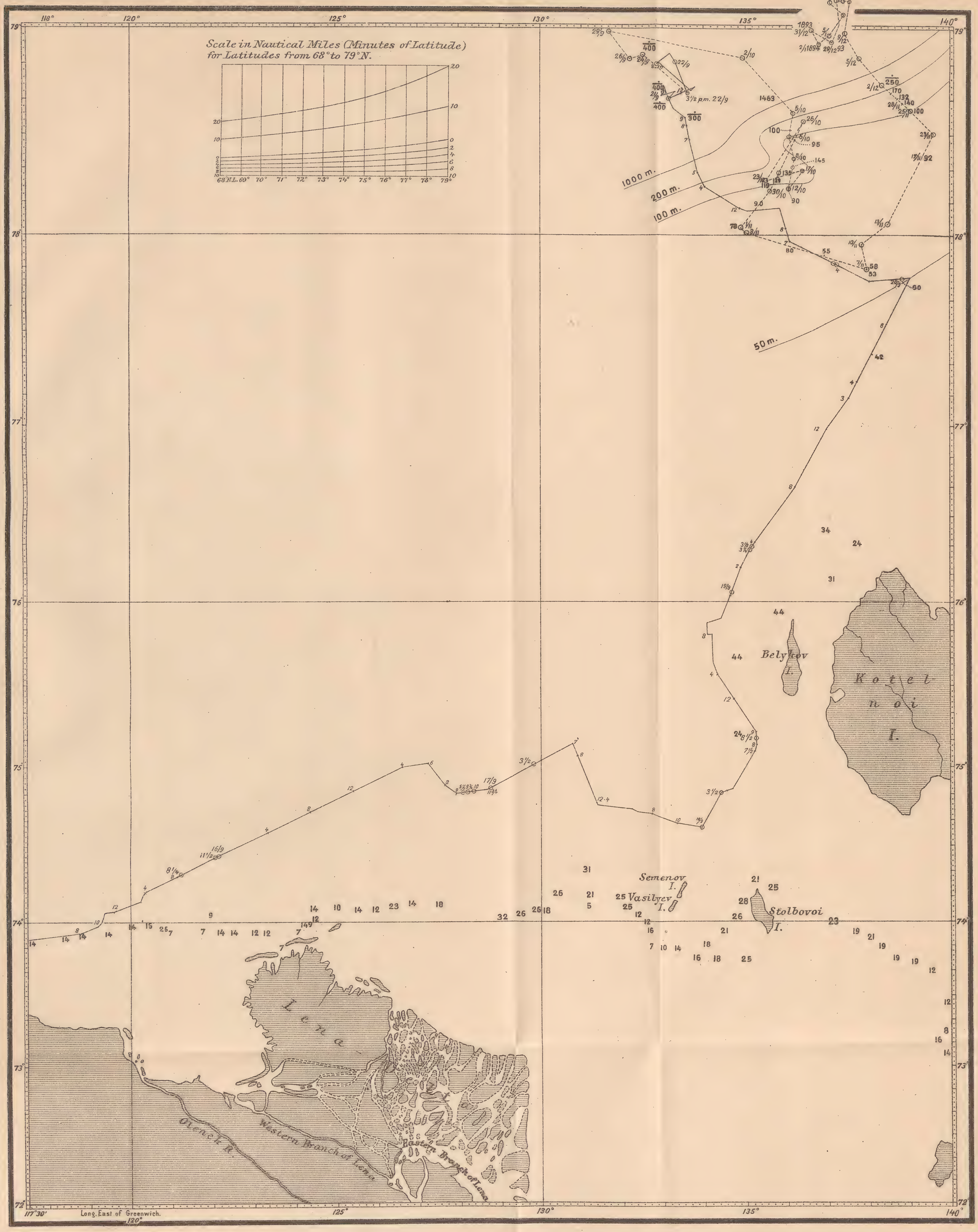
Figh in Metres.
Figoon and the Hour (8).
The cated by a ring thus, —o—



TRACK OF THE FRAM FROM AUGUST 26 (26/8), TO SEPTEMBER 15 (15/9), 1893.

Figures in erect letters thus, 52, *along the starbord side of the Fram's track and elsewhere, indicate the Depth in Metres.*
Figures in italics thus, 10/8 *and* 8, *along the port side of the Fram's track, indicate the Date (10/8) for every noon and the Hour (8).*
The Fram's Track in open water shown thus, ←✓ *Position determined by astronomical observation, is indicated by a ring thus,* —○—


Scale in Nautical Miles (M
for Latitudes from 68° to 79°
68°N.L. 69° 70° 71° 72° 73° 74°
118° 120° 125° 135° 140°
79° 78° 77° 76°
1893
1920
1894
1463
3½ p.m. 22/9
100 m.
50 m.
Belyakov I.
Kotel



TRACK OF THE FRAM FROM SEPTEMBER 15 (15/9), 1893, TO JANUARY 13 (13/1), 1894.

Figures in erect letters thus, 52, along the starbord side of the Fram's track and elsewhere, indicate the Depth in Metres.
Figures in italics thus, 10/8 and 8, along the port side of the Fram's track, indicate the Date (10/8) for every noon and the Hour (8).
The Fram's Track in open water shown thus, ——— Position determined by astronomical observation, is indicated by a ring thus, ——o——
The Fram's Track while drifting with the ice, shown thus, ------

The Norwegian North Pola

80°N.L.

m. 3400

0
100
200
300
400
500
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400

L.

75°N.L.

74°N.L.

16 21 Lena Delta

No 5

Lena Delta to 80°2'N.L. & 135°20'E.L.

22 Kotelnoi

No 4

noi to 82°6'N.L. and 128°E.L.

72°N.L. 71°N.L.

m. 0 100 200 300

69 48 48 35
243 49 46 42 51 53 55 57 37 35

Belcher P.

No 1.

Belcher Point to 72°44'N.L. and 159°10'W.L.

V.L. 69°N.L. 68°N.L.

Siberian Coast

51 53 55 53 55 51 49 51 37 38 9 7

No 2

Siberian Coast to 73°50'N.L. and 172°30'W.L.

76°N.L. 71°N.L. 70°N.L.

m. 0 100 200

26 22 21 20 14 14 14 16 20 Siberian Coast

No 3

Siberian Coast to 75°53'N.L. and 169°45'E.L.

Beli Ostrov

229 238 229 26 37 29 20 29 33 20 22 18 22 15 24 5

No 6

Beli Ostrov to Novaya Zemlya

Kanin Nos

73 79 90 82 86 69 64 59 55 40 4

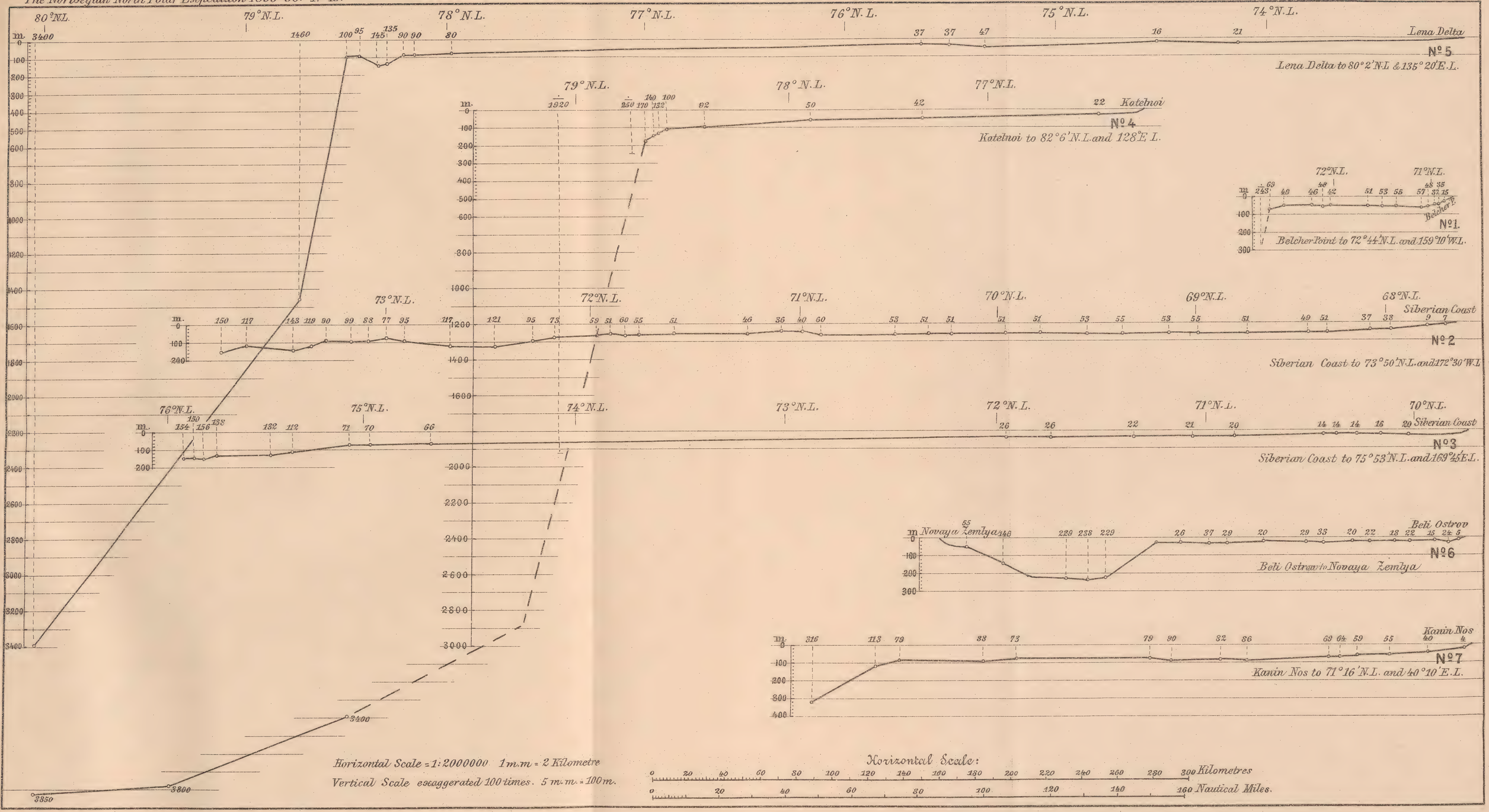
No 7

Kanin Nos to 71°16'N.L. and 40°10'E.L.

3850

0 220 240 260 280 300 Kilometres

120 140 160 Nautical Miles.


80°N.L.
79°N.L.
78°N.L.
77°N.L.
76°N.L.
75°N.L.
74°N.L.
m.
3400
1460
100 95
145 135
90 90
80
37 37 47
16
21
Lena Delta
N° 5
Lena Delta to 80°2'N.L & 135°20'E.L.
79°N.L.
78°N.L.
77°N.L.
1320
250 110 140 132 100
92
50
42
22
Kotelnoi
N° 4
Kotelnoi to 82°6'N.L.and 128°E.L.
72°N.L.
71°N.L.
63
243
49
48 46 42
51 53 56
48 35 57 37 35
Belcher P.
N° 1.
Belcher Point to 72°44'N.L.and 159°10'W.L.
73°N.L.
72°N.L.
71°N.L.
70°N.L.
69°N.L.
68°N.L.
Siberian Coast
150 117 143 119 90 99 88 77 95 117
121 95 73 59 54 60 55 51 46 36 40 60 53 51 51 51 51 53 55 53 55 51 49 52 37 38 9 7
N° 2
Siberian Coast to 73°50'N.L.and172°30'W.L
76°N.L.
75°N.L.
74°N.L.
73°N.L.
72°N.L.
71°N.L.
70°N.L.
Siberian Coast
150
154 156 138
132 112 71 70 66
26 26 22 21 20 14 14 14 16 20
N° 3
Siberian Coast to 75°53'N.L.and169°45'E.L.
55
Novaya Zemlya
146
229 238 229
26 37 29 20 29 33 20 22 18 22 15 24 5
Beli Ostrov
N° 6
Beli Ostrov to Novaya Zemlya
316
113 79 33 73 79 90 82 86 63 64 59 55 40 4
Kanin Nos
N° 7
Kanin Nos to 71°16'N.L. and 40°10'E.L.
3400
3350
3800
Horizontal Scale: 1:2000000 1 m.m = 2 Kilometre
Vertical Scale exaggerated 100 times. 5 m.m. = 100 m.
Horizontal Scale:
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 Kilometres
0 20 40 60 80 100 120 140 160 Nautical Miles.

Sg = Shingle or Gravel
St = Stone
Fj = Rock or Hard Bottom
f. S = Fine Sand
g. S = Coarse Sand
} S = Sand
L = Clay
Sl = Mud and Ooze
S L = Sand and Clay

Hjerttind 1387

Tromsdalstind 1246

Blaamanden 1057

Finlandsfjeld 790

Österaas 480

Tromsövarde 147

Vengs-ö

Kval Ö

Nordmandsfjord-jekke 1075

Baarsfjordfj. 869

Borgefj. 651

653 Vatnefj.

Korsagfj. 651

Borgestak 552

Himmelhaugen 397

Ölksfj. 384

Sörö

Nº 10

Graakoldfj. 417

Honningsvaagfj. 390

Urfj. 395

Fisketind 490

North Cape 307

North Cape

Nº 9

From North Cape Northward

Skibskjölen 636

Övre Tavla 418

404 Langryggen

Kyst Tavla 360

Munken 142

Nº 8

From Sylte Fjord on Varanger Peninsul towards N.E

Long. Section

Nº 11

m. 2886 2165 619 828 235 384 115 126 96 75 62 62 109 60

St. Fj. gS. Fj. S. Sg. St. S. Sl. Sl. Sl. Sl.

m. 430 293 290 209 73 62 30 64 31 47

S. S. S. St. S. S. f. S.

284 288 286 274 286 310

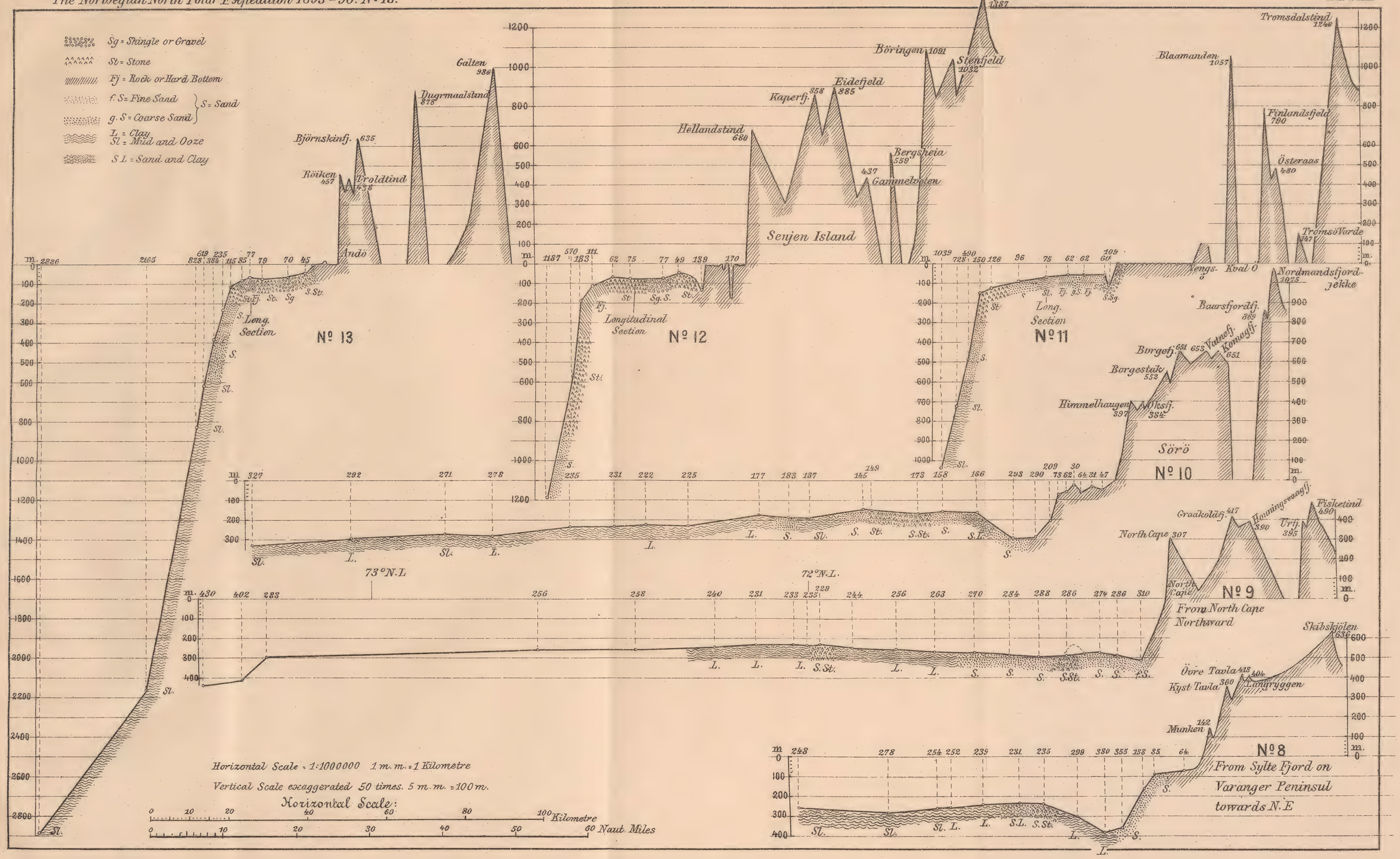
S. S. S. St. S. S. f. S.

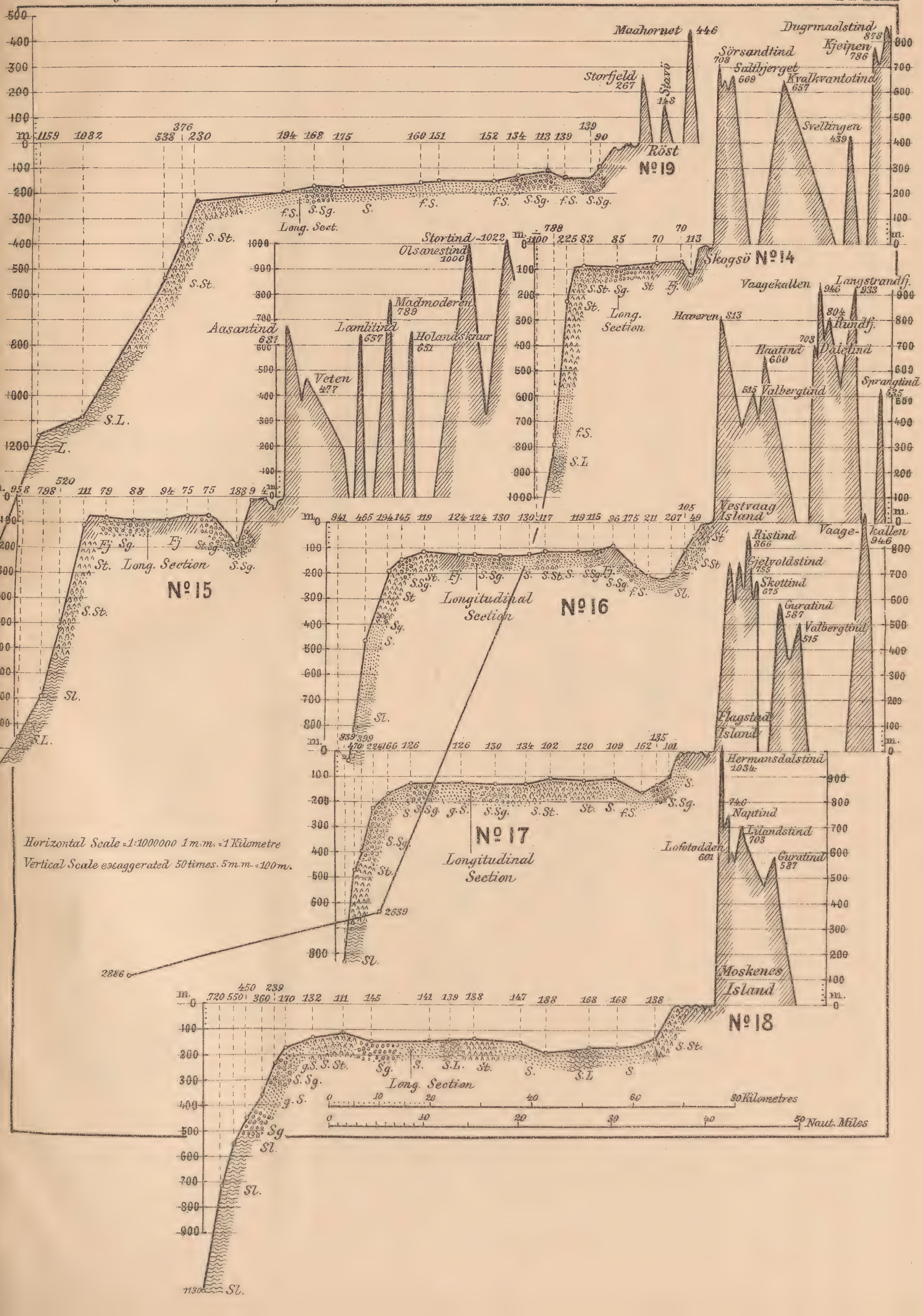
231 235 299 380 355 158 85 64

S. L. S. St. L. S. L.

0 10 20

0 10


Sg = Shingle or Gravel
St = Stone
Fj = Rock or Hard Bottom
f. S = Fine Sand
g. S = Coarse Sand
S = Sand
L = Clay
Sl = Mud and Ooze
S L = Sand and Clay
Nº 13
Nº 12
Nº 11
Nº 10
Nº 9
Nº 8
Senjen Island
Long. Section
Longitudinal Section
Sörö
From North Cape Northward
From Sylte Fjord on Varanger Peninsul towards N.E
73° N.L
72° N.L.
Horizontal Scale = 1:1000000 1 m.m. = 1 Kilometre
Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.
Horizontal Scale:
Kilometre
Naut. Miles


Maahornet 446
Dugrmaalstind 878
Kjeinen 786
Sörsandtind 708
Saltbjerget 669
Kvalkvantotind 657
Svelbingen 439
Storfjeld 267
Stavö 148
Röst
№ 19
Skogsö № 14
Stortind 1022
Olsanestind 1000
Madmoderen 789
Lamkitind 657
Holandskaar 651
Aasantind 681
Veten 477
Long. Sect.
S. St.
S. L.
L.
Sl.
Vaagekallen
Langstrandfj. 946
Haveren 813
804 Rundfj.
703 Dalelind
Haatind 660
515 Valbergtind
Sprangtind 535
Long. Section
№ 15
Longitudinal Section
№ 16
Vestvaag Island
Ristind 866
Gjelvoldstind 755
Skottind 675
Guratind 587
Valbergtind 575
Flagstad Island
Hermansdalstind 1034
Naptind 746
Litlandstind 703
Lofotodden 601
Guratind 587
Moskenes Island
№ 18
№ 17
Longitudinal Section
Horizontal Scale = 1:1000000 1 m.m. = 1 Kilometre
Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.
Long. Section
0 10 20 40 60 80 Kilometres
0 10 20 30 40 50 Naut. Miles

Sg. = Shingle or

St. = Stone

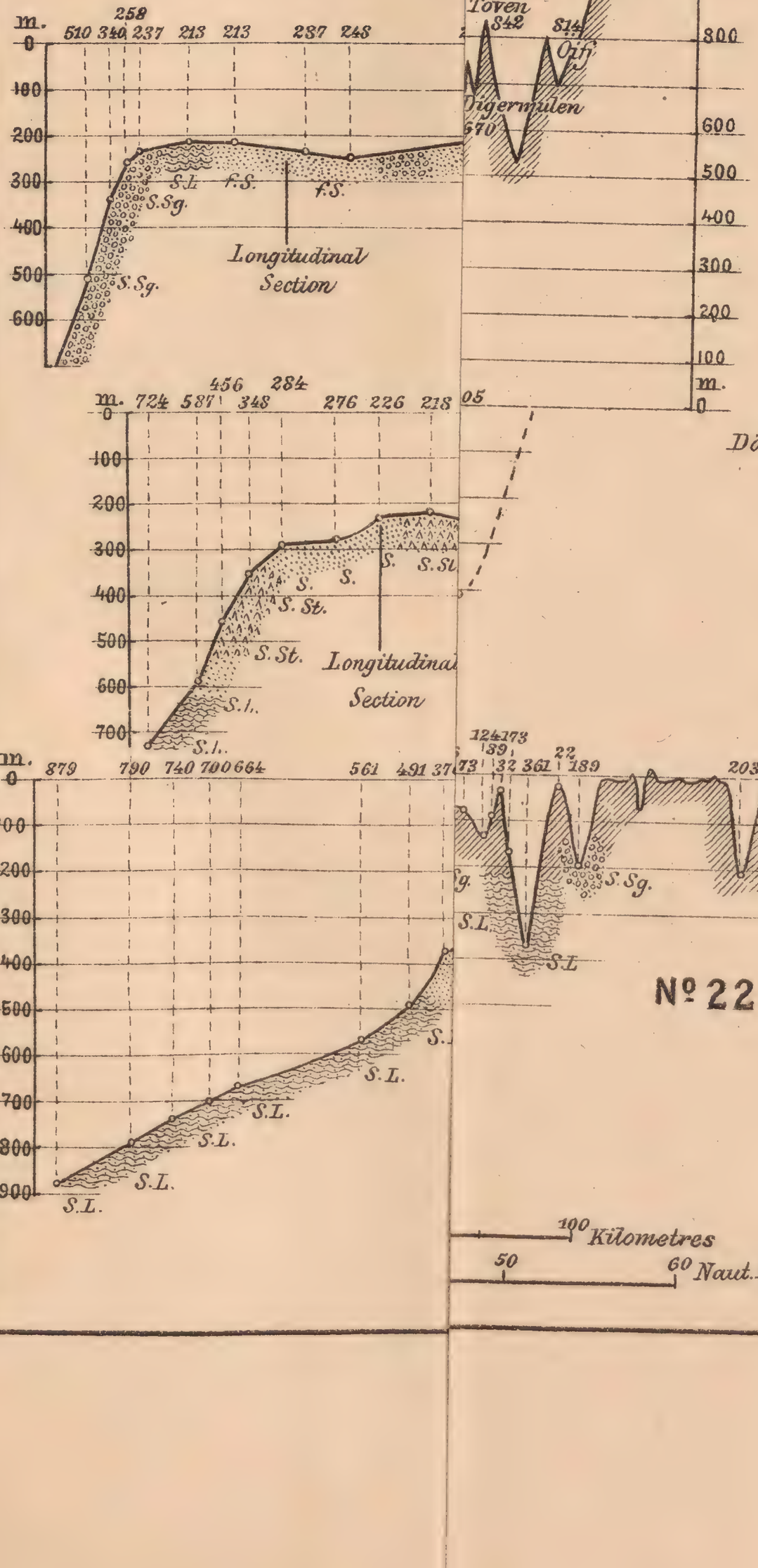
Fj. = Rock or H

f.S. = Fine Sa

g.S. = Coarse S

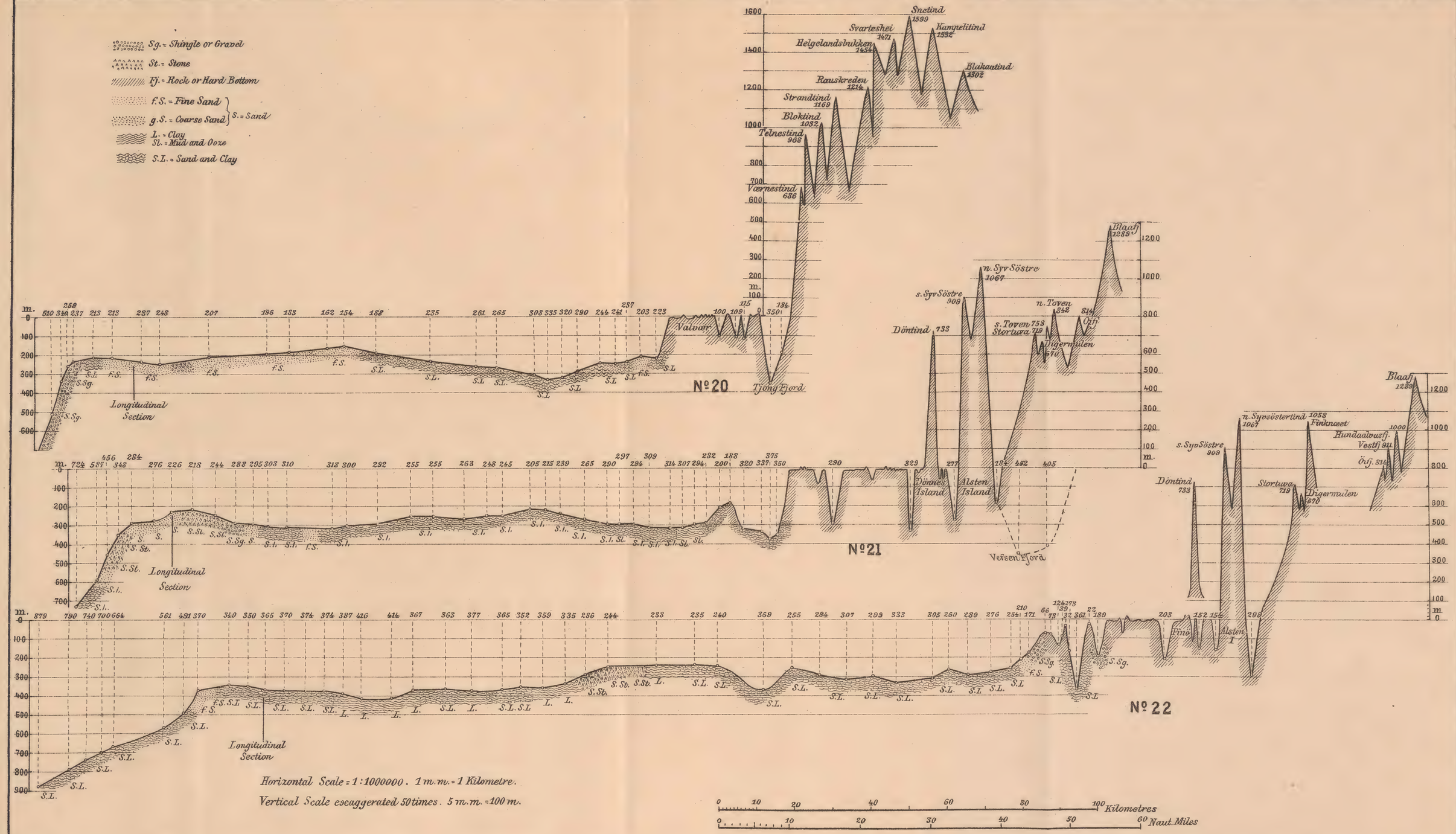
L. = Clay
Sl. = Mud and

S.L. = Sand an

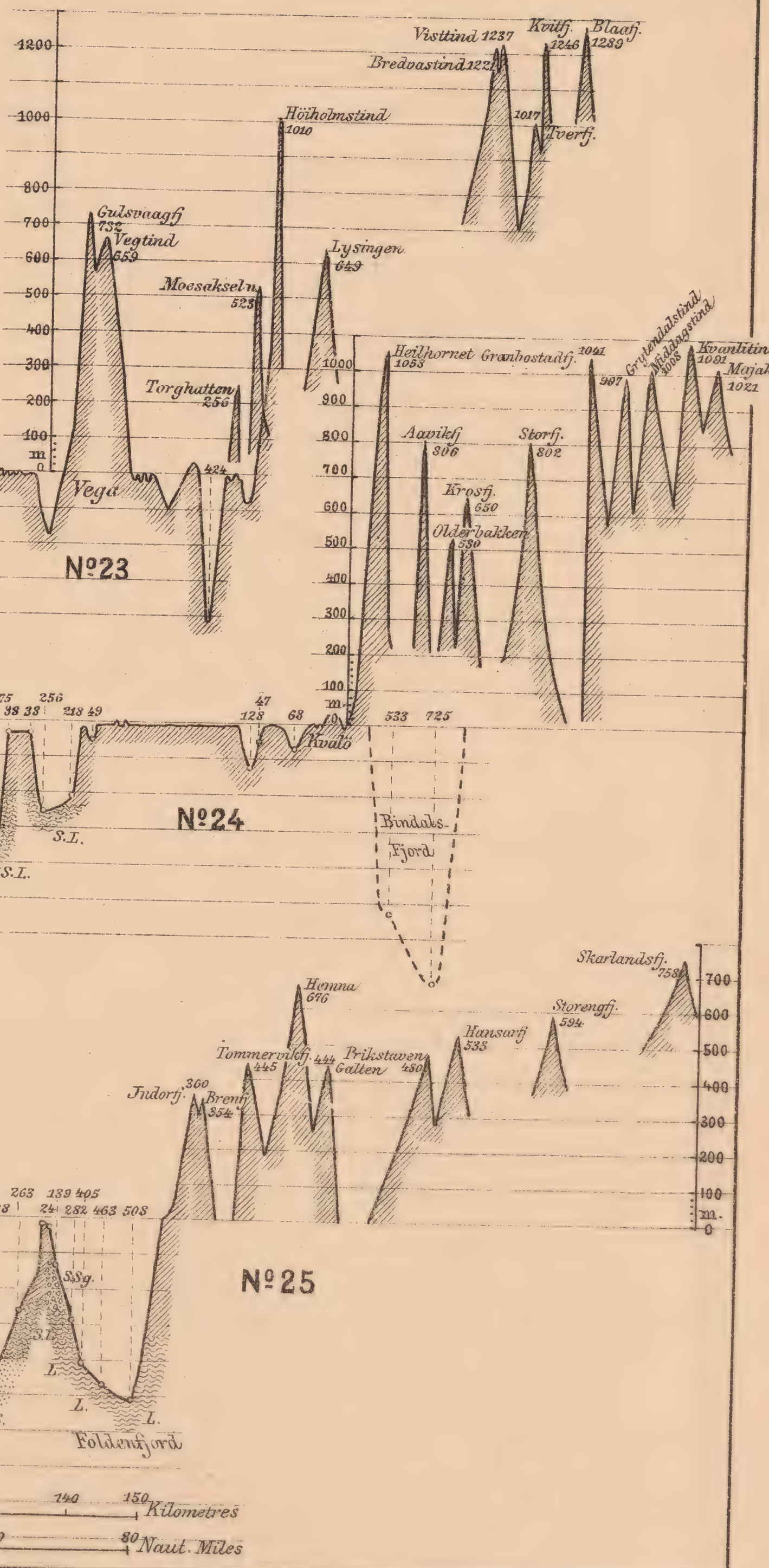


Nº 22

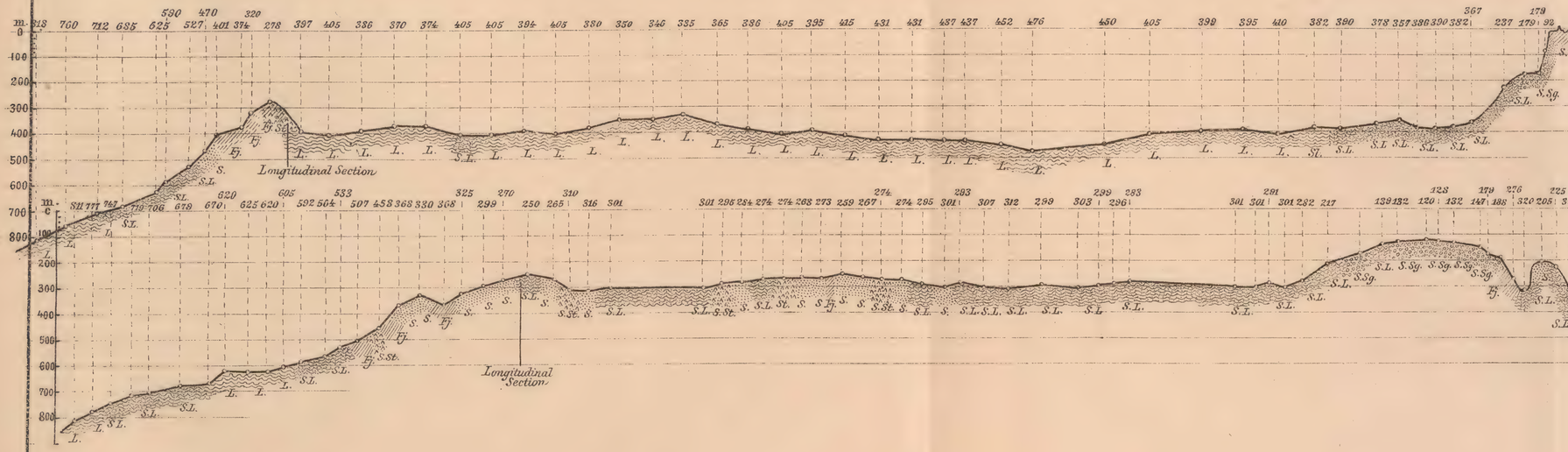
Sg. = Shingle or Gravel
St. = Stone
Fj. = Rock or Hard Bottom
f.S. = Fine Sand
g.S. = Coarse Sand
S. = Sand
L. = Clay
Sl. = Mud and Ooze
S.L. = Sand and Clay

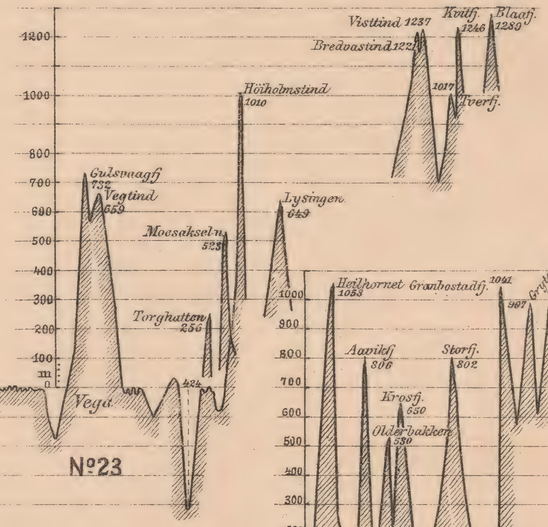


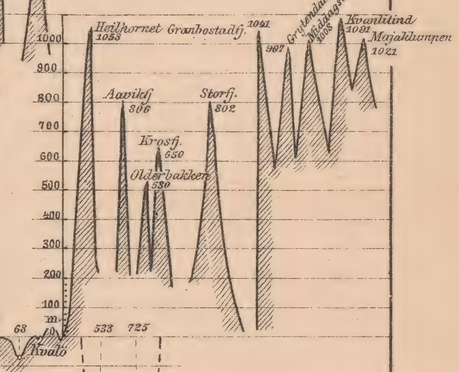
Sg. = Shi
St. = Stor
Fj. = Roc
f.S. = Fin
g. S. = Co
L. Clay
Sl. = Mud
S.L. = San

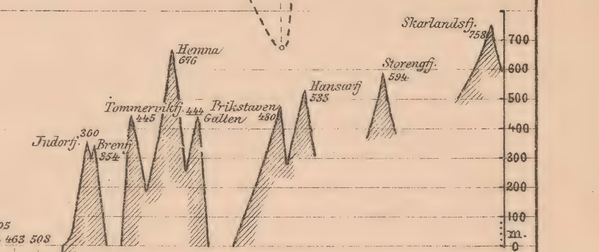


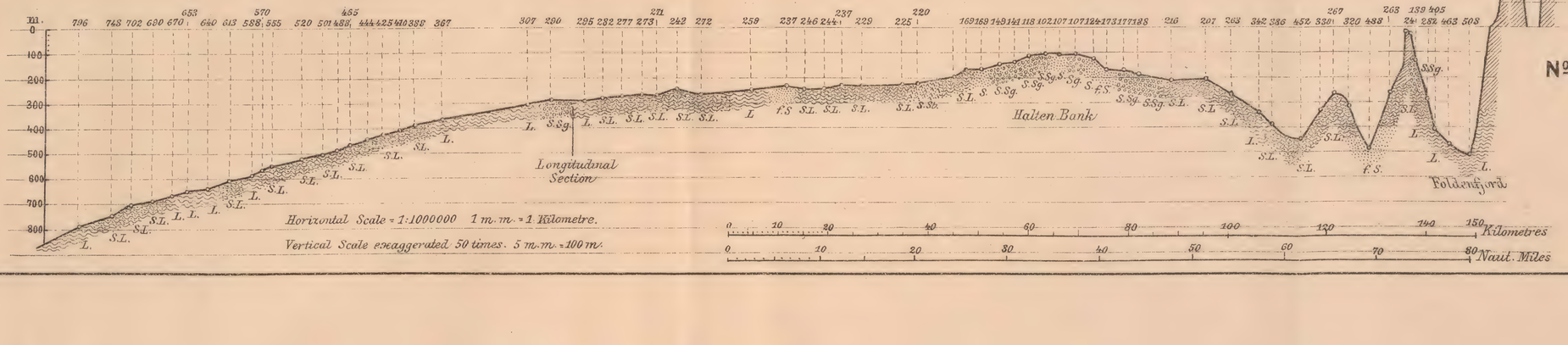
Sg. = Shingle or Gravel
St. = Stone
Fj. = Rock or Hard Bottom
f. S. = Fine Sand
g. S. = Coarse Sand
} S. = Sand
L. Clay
Sl. = Mud and Ooze
S.L. = Sand and Clay







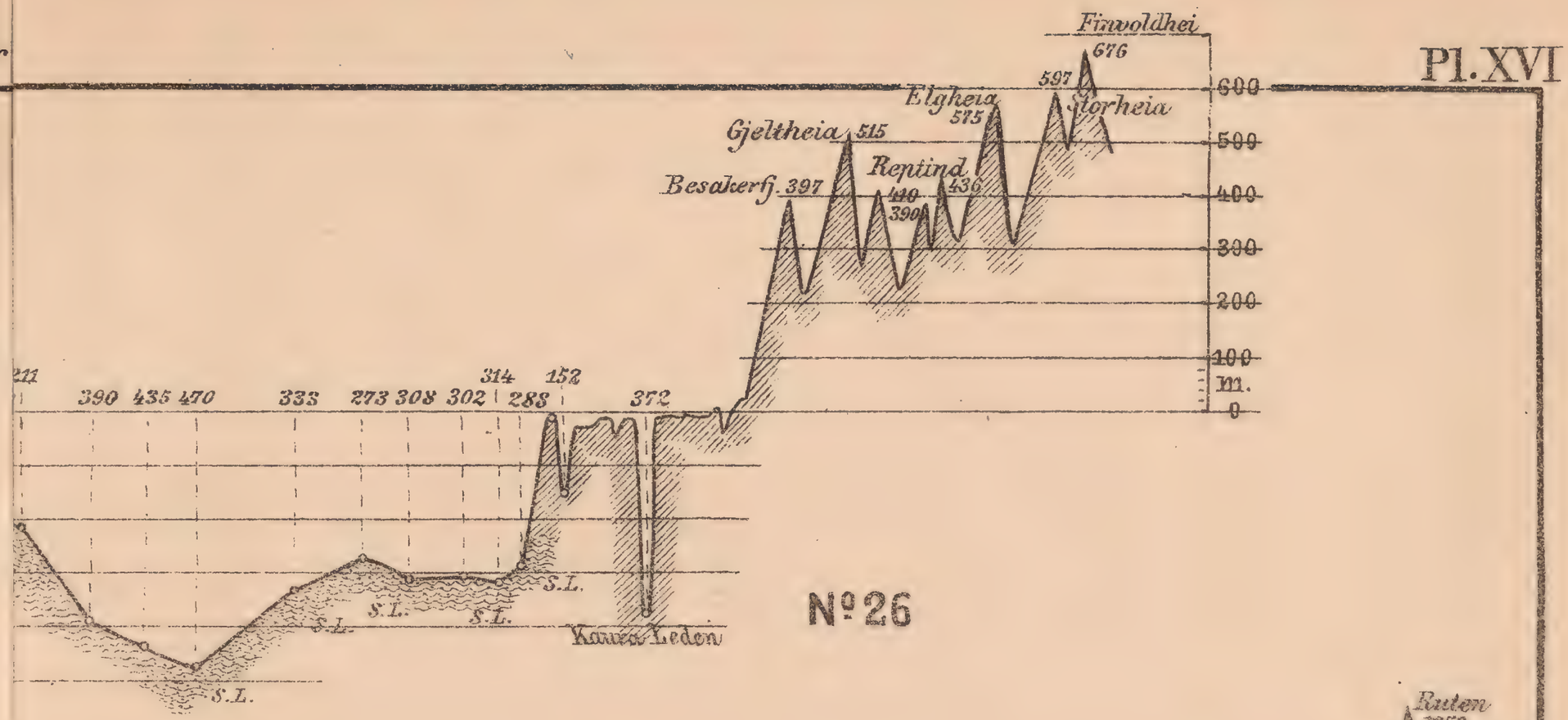




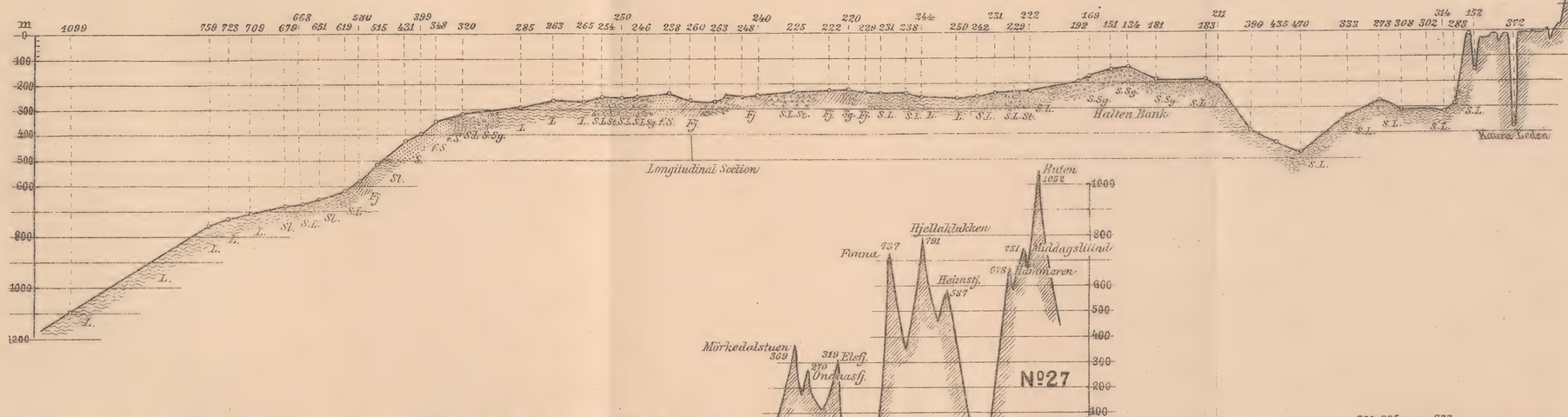
Horizontal Scale = 1:1000000 1 m.m. = 1 Kilometre.
Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.

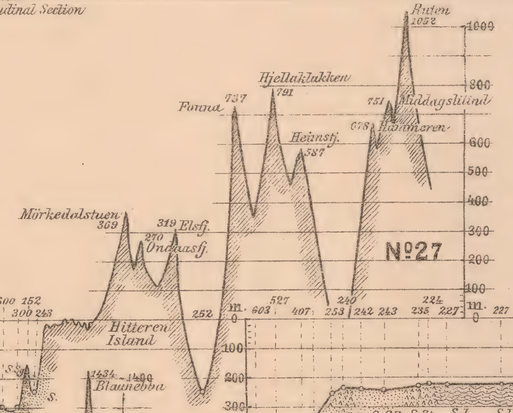
0 10 20 40 60 80 100 120 140 150 Kilometres
0 10 20 30 40 50 60 70 80 Naut. Miles

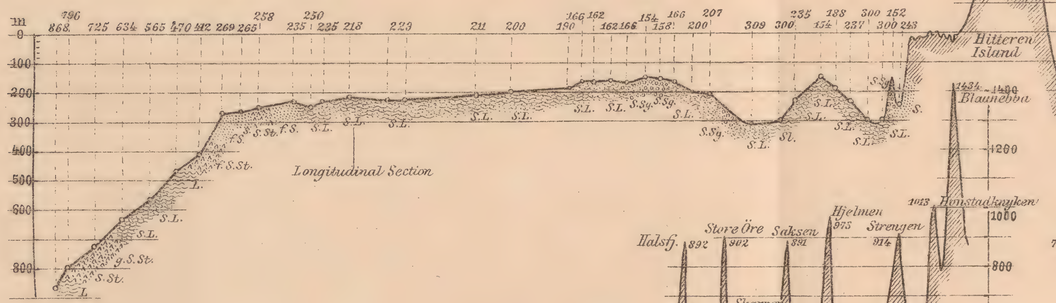
Sg. = Shingle or Gravel
St. = Stone
Fj. = Roch or Hard Bottom
f.S. = Fine Sand } S. Sand
g.S. = Coarse Sand }
L. = Clay
Sl. = Mud and Ooze
S.L. = Sand and Clay

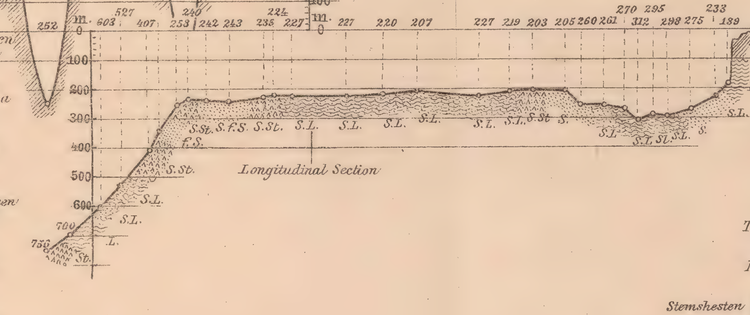


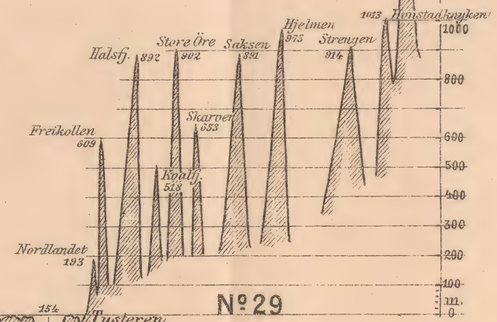
Sg. = Shingle or Gravel
St. = Stone
Fj. = Rock or Hard Bottom
f.S. = Fine Sand } S. Sand
g.S. = Coarse Sand }
L. = Clay
Sl. = Mud and Ooze
S.L. = Sand and Clay

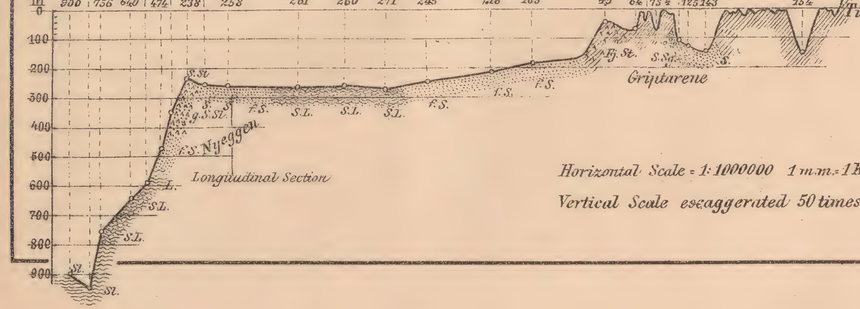


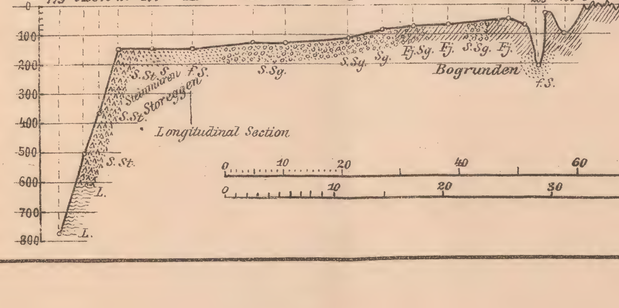


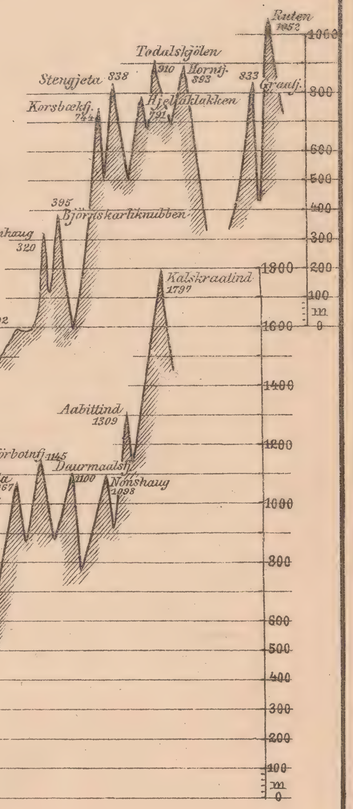








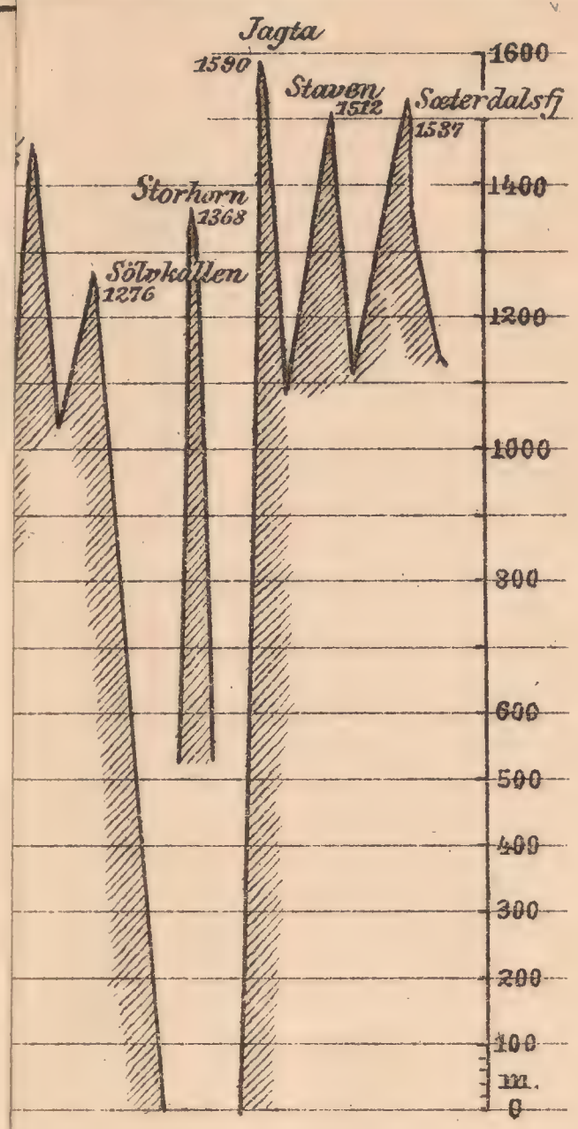


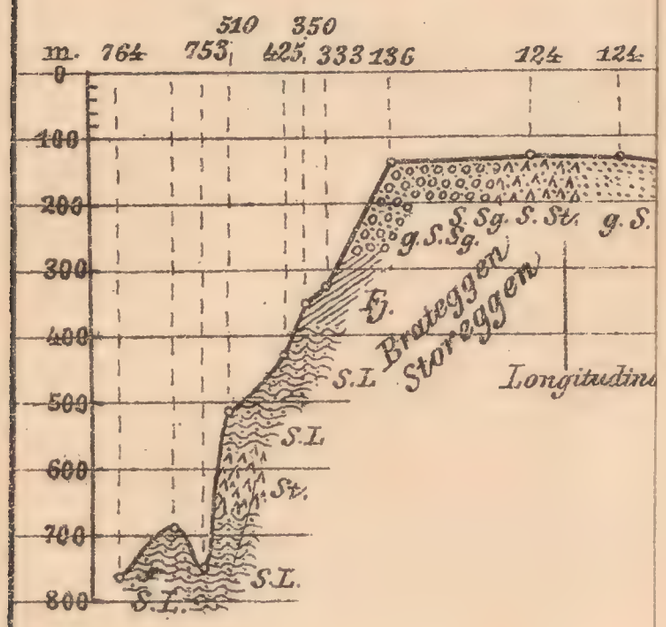


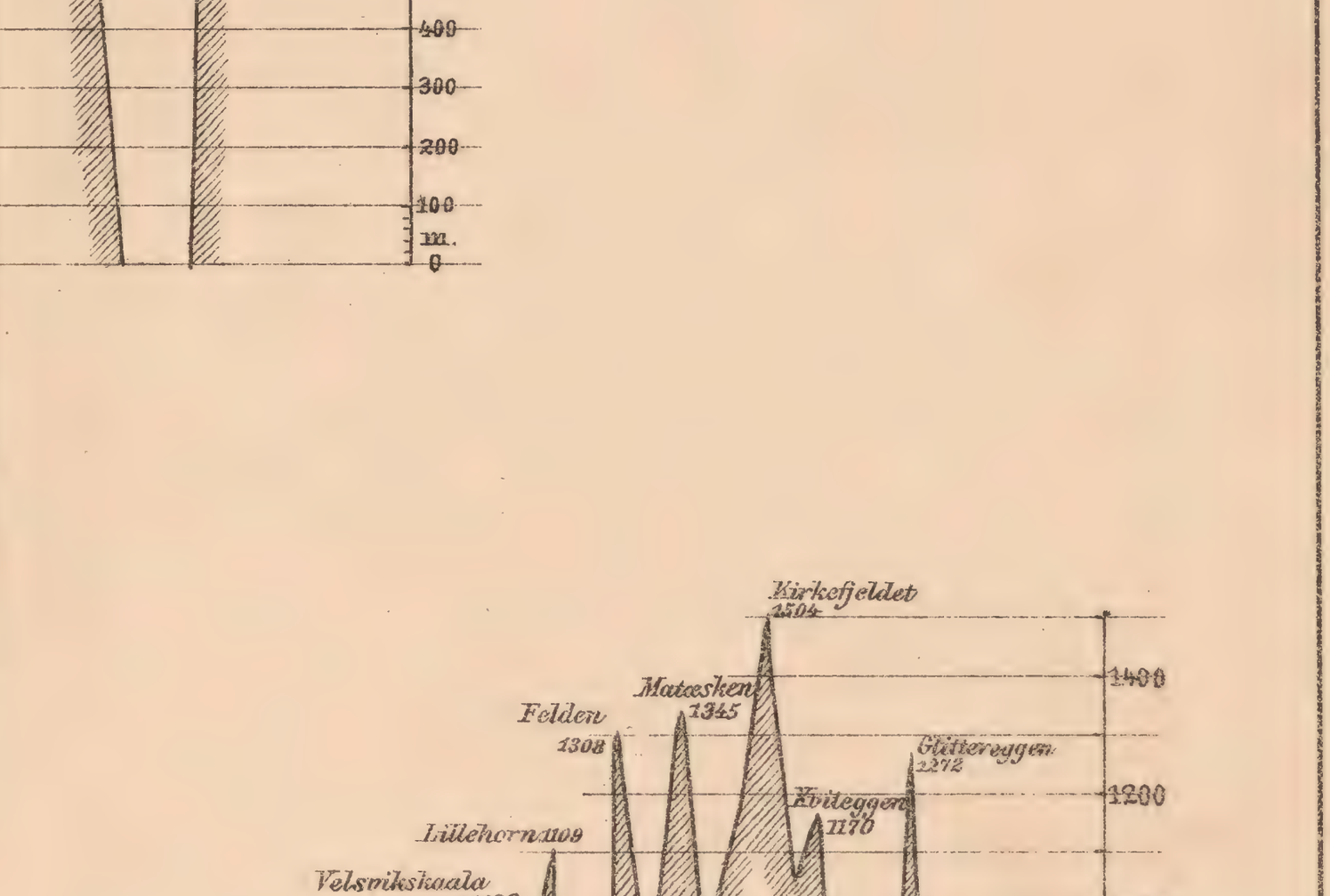
Horizontal Scale = 1: 1000000 1 m.m. = 1 Kilometre
Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.

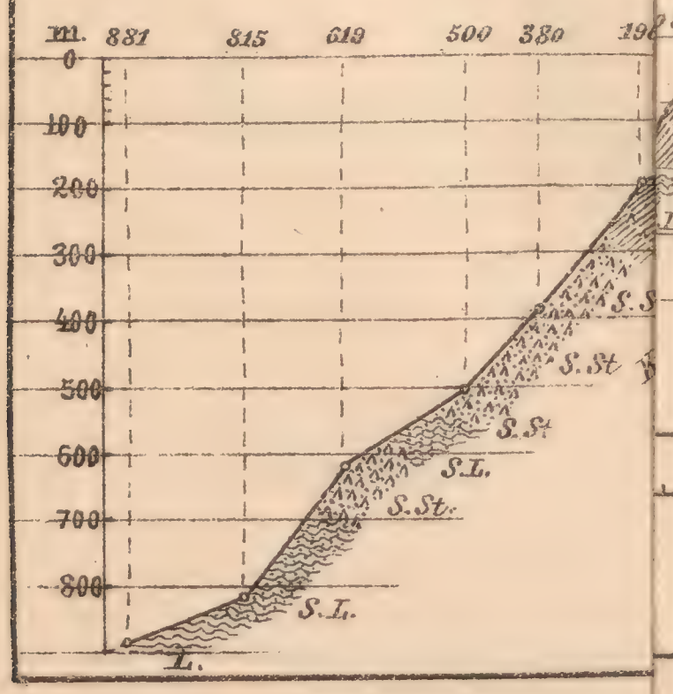
0 10 20 40 60 80 100 Kilometres
0 10 20 30 40 50 60 Naut. Miles

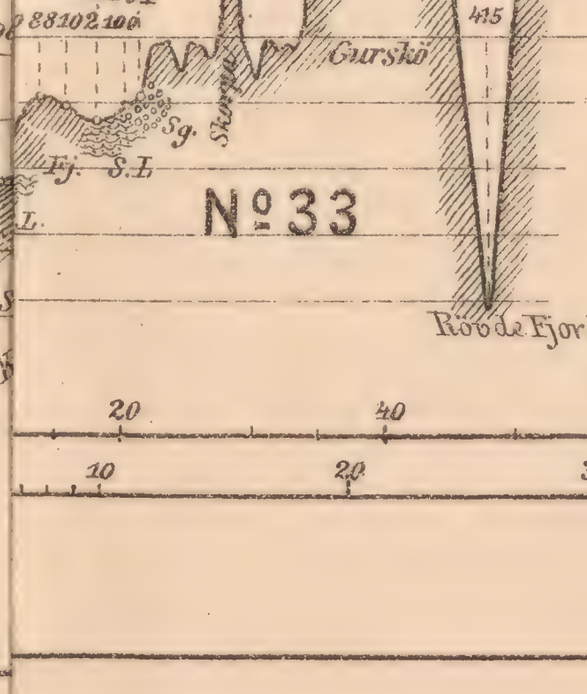
Sg = Shingle or Gravel
St = Stone
Fj. = Rock or Hard Bottom
f. S. = Fine Sand
g. S. Coarse Sand
L = Clay
Sl. Mud and Ooze
S.L. = Sand and Clay









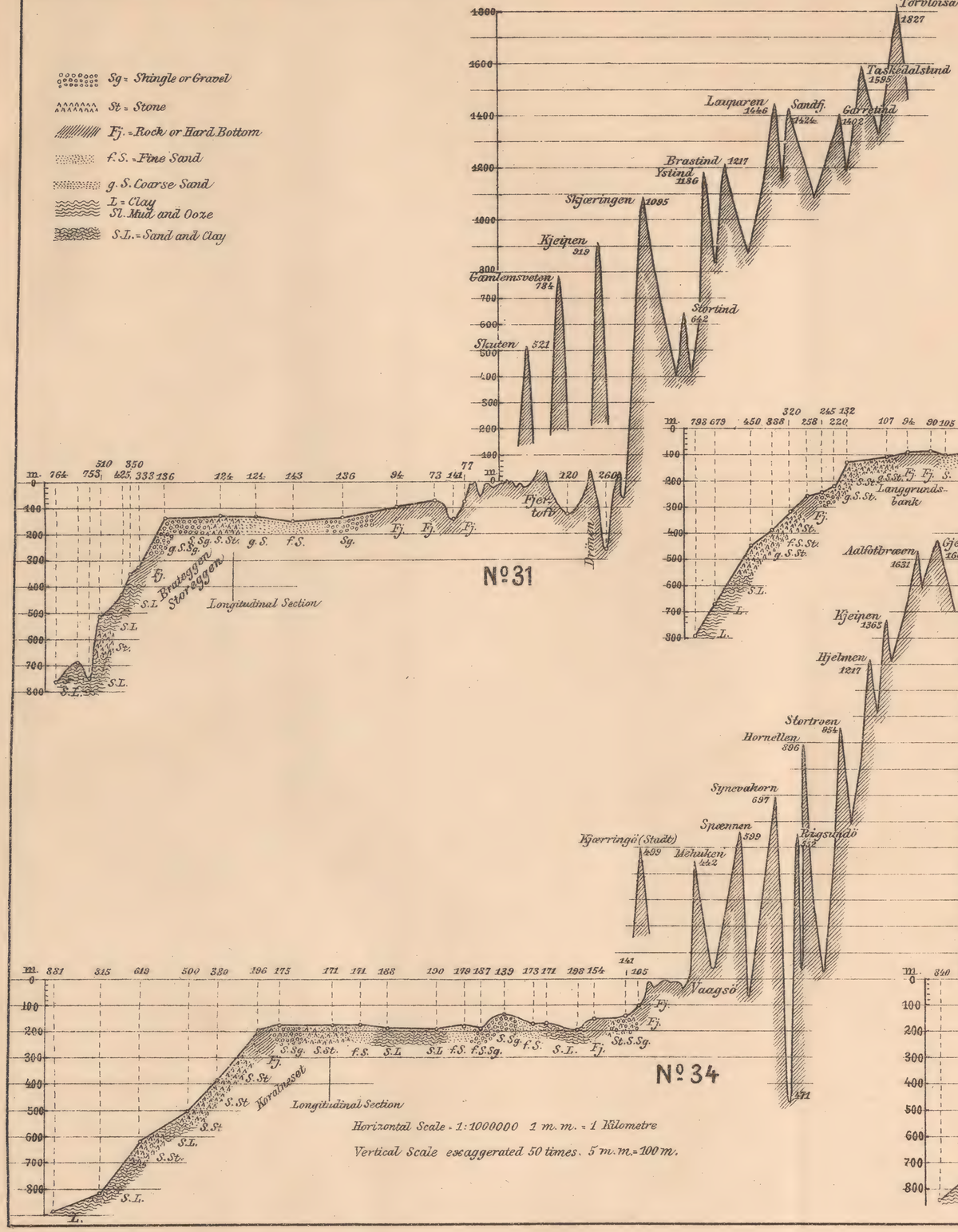


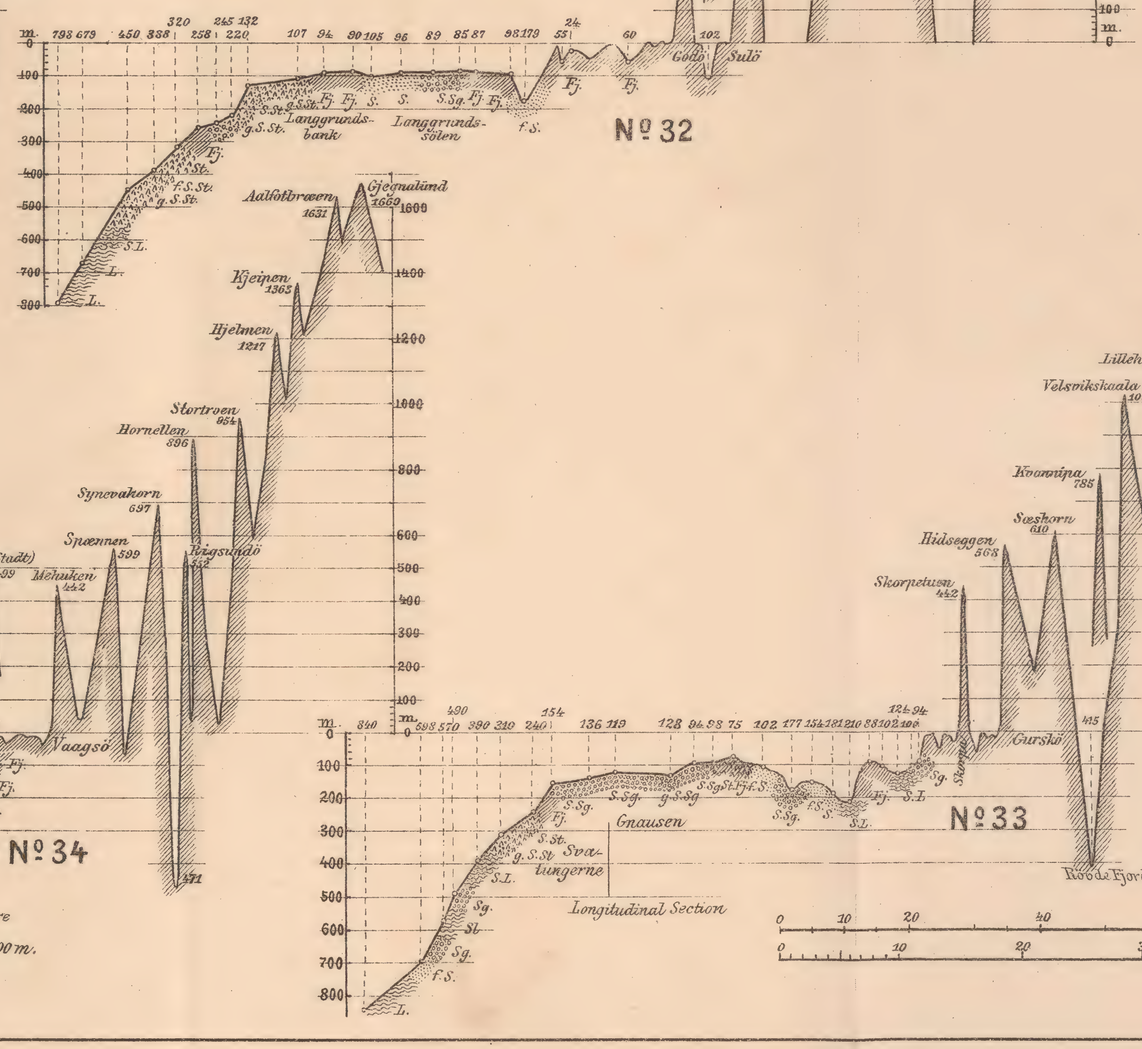
No 33

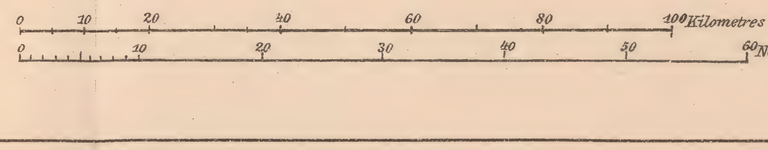
Rovde Fjord

20 40 60 80 100 Kilometres
10 20 30 40 50 60 Naut. Miles

Sg = Shingle or Gravel
St = Stone
Fj. = Rock or Hard Bottom
f.S. = Fine Sand
g.S. Coarse Sand
L = Clay
Sl. Mud and Ooze
S.L. = Sand and Clay







Horizontal Scale - 1:1000000 1 m.m. = 1 Kilometre

Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.

62°25'N.Lat. 2°56'E.Long

63° N.Lat.

Langgrund Bank

Section N°34 Section N°33 Section N°32 Section N°31 Section N°30 Section N°F

Storegyen

64° N.Lat. 65° N.Lat.

Section N°F Section N°29 Section N°28 Section N°27 Section N°E Section N°26 Section N°25

64° N.Lat. 65° N.Lat.

Section N°24 Section N°D Section N°23 66° N.Lat. Section N°22

67° N.Lat. Section N°21 Section N°C Section N°20 Section N°19

Moskenes Bank Flagstad Bank Langö Bank Skogsö Bank

68° N.Lat. Section N°18 Section N°17 Section N°16 Section N°15 Section N°14 69° N.Lat.

70°20'N.Lat 18°8'E.Long

Andö Bank Senjen Bank Malangen Bank

Section N°13 Section N°12 Section N°11

And Fjord Malangen Submarine Fjord 70° N.Lat.

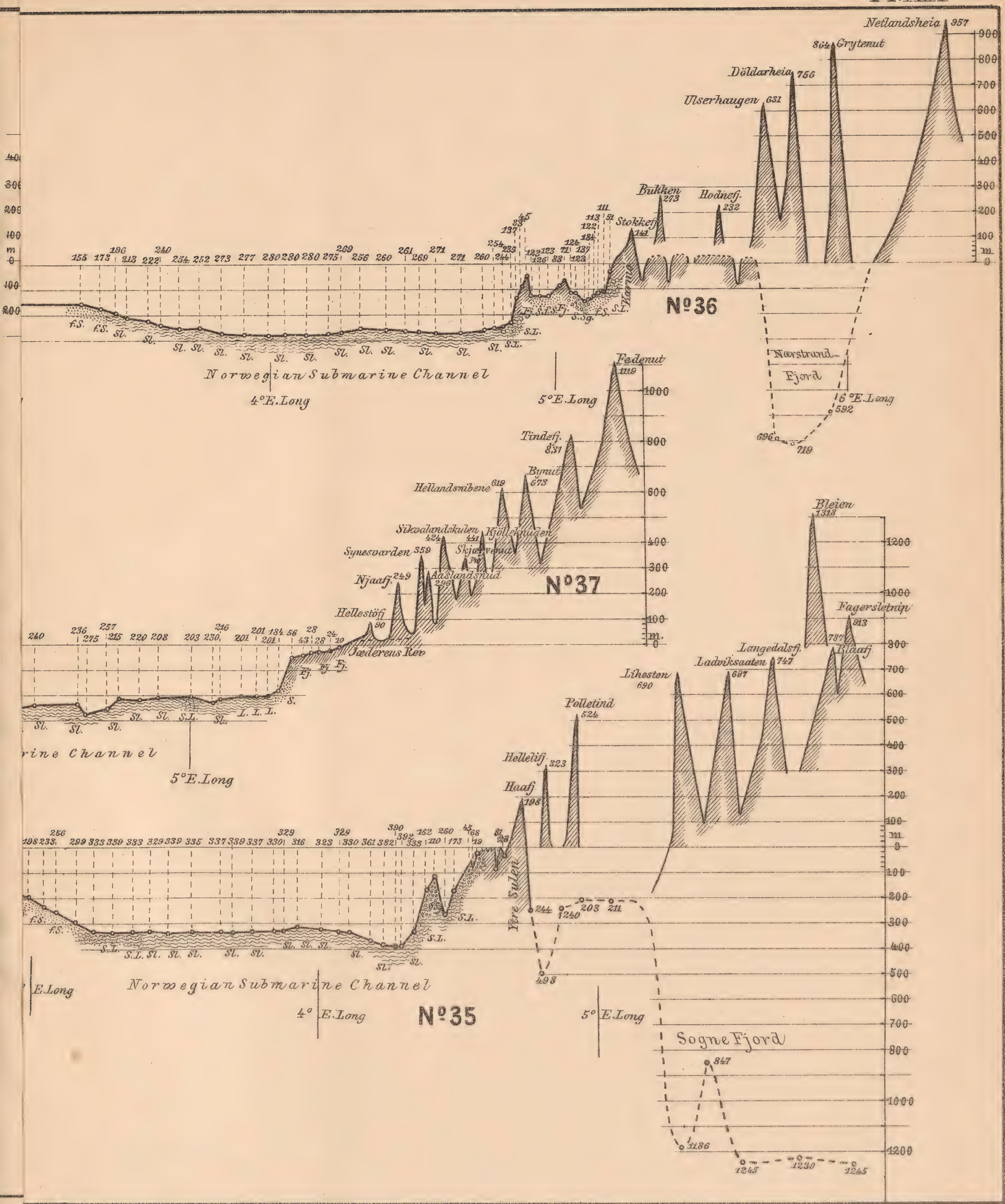
Horiz. Scale = 1:1,000,000. 1 m.m. = Kilom.

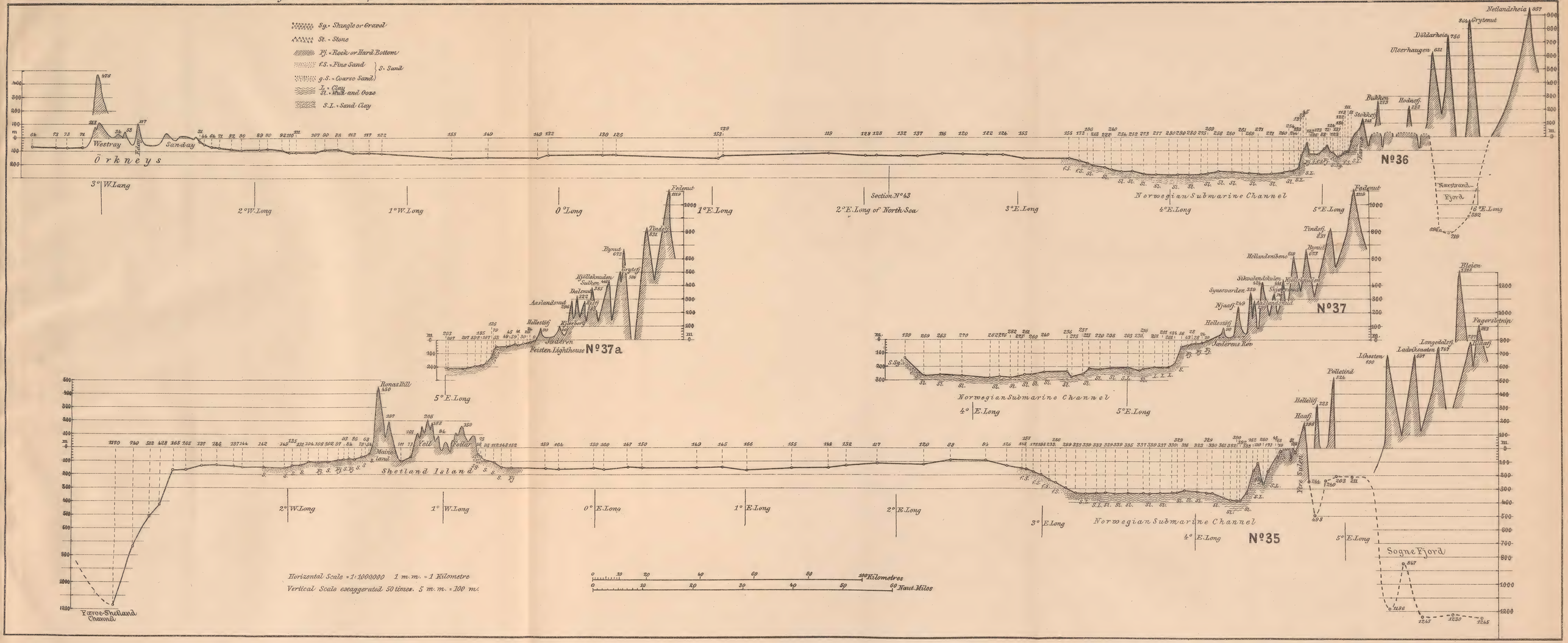
Vertic. Scale exaggerated 50 times. 5 m.m. = 100 m.

0 10 20 40 60 80 Kilometres

0 10 20 30 40 50 Naut. Miles

Longitudinal Section along the Norwegian Continental Shelf near its edge, from 62°25'N.Lat. and 2°56'E.Long. to 70°20'N.Lat. and 18° 8' E. Long.


Netlandsheia 957
Grytenut 864
Döldarheia 756
Ulserhaugen 631
Bukken 273
Hodnefj. 232
Stokkefj 141
Fedenut 1119
Tindefj. 831
Bymüt 673
Hellandsnibene 619
Sikvalandskulen 424
Kjölleknuden 441
Synesvarden 359
Njaafj. 249
Aaslandsnud 296
Hellestöfj 90
Fæderens Rev
Norwegian Submarine Channel
4° E. Long
5° E. Long
6° E. Long
Nærstrand-Fjord
592
696
719
Nº36
Nº37
Nº35
Bleien 1318
Fagersletnip 813
Blaafj. 787
Langedalsfj. 747
Ladviksaaten 697
Lihesten 690
Polletind 524
Helleljf 323
Haafj 198
Ytre Sulen
244
240
203
211
498
Sogne Fjord
847
1186
1245
1230
1245


Sg. = Shingle or Gravel
St. = Stone
Fj. = Rock or Hard Bottom
f.S. = Fine Sand
g.S. = Coarse Sand
S. Sand
L. = Clay
Sl. = Mud and Ooze
S.L. = Sand Clay
Westray
Sanday
Örkneys
3° W. Long
2° W. Long
1° W. Long
0° Long
1° E. Long
2° E. Long of North Sea
Section No 43
3° E. Long
4° E. Long
5° E. Long
6° E. Long
Norwegian Submarine Channel
No 36
Nærstrand Fjord
Netlandsheia
Grytemut
Döldarheia
Ulserhaugen
Bukken
Hodnefj.
Stokkefj.
Fedemut
Tindefj.
Bymut
Grytefj.
Kjölleknuden
Sulken
Dalsnut
Aaslandsnut
Hellestöfj.
Kjærberg
Jæderen
Feisten Lighthouse
No 37 a
Hellandsnibene
Sikvalandskulen
Synesvarden
Njaafj.
Hellestöfj.
Jæderens Rev
No 37
Bleien
Fagersletnip
Blaafj.
Langedalsfj.
Ladviksaaten
Lihesten
Polletind
Hellelifj.
Haafj.
Yere Sulen
Sogne Fjord
Ronas Hill
Mainland
Yell
Fetlar
Shetland Island
Færoe-Shetland Channel
No 35
Horizontal Scale = 1:1000000 1 m.m. = 1 Kilometre
Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.
Kilometres
Naut. Miles

Sg. = Shingle or Gravel

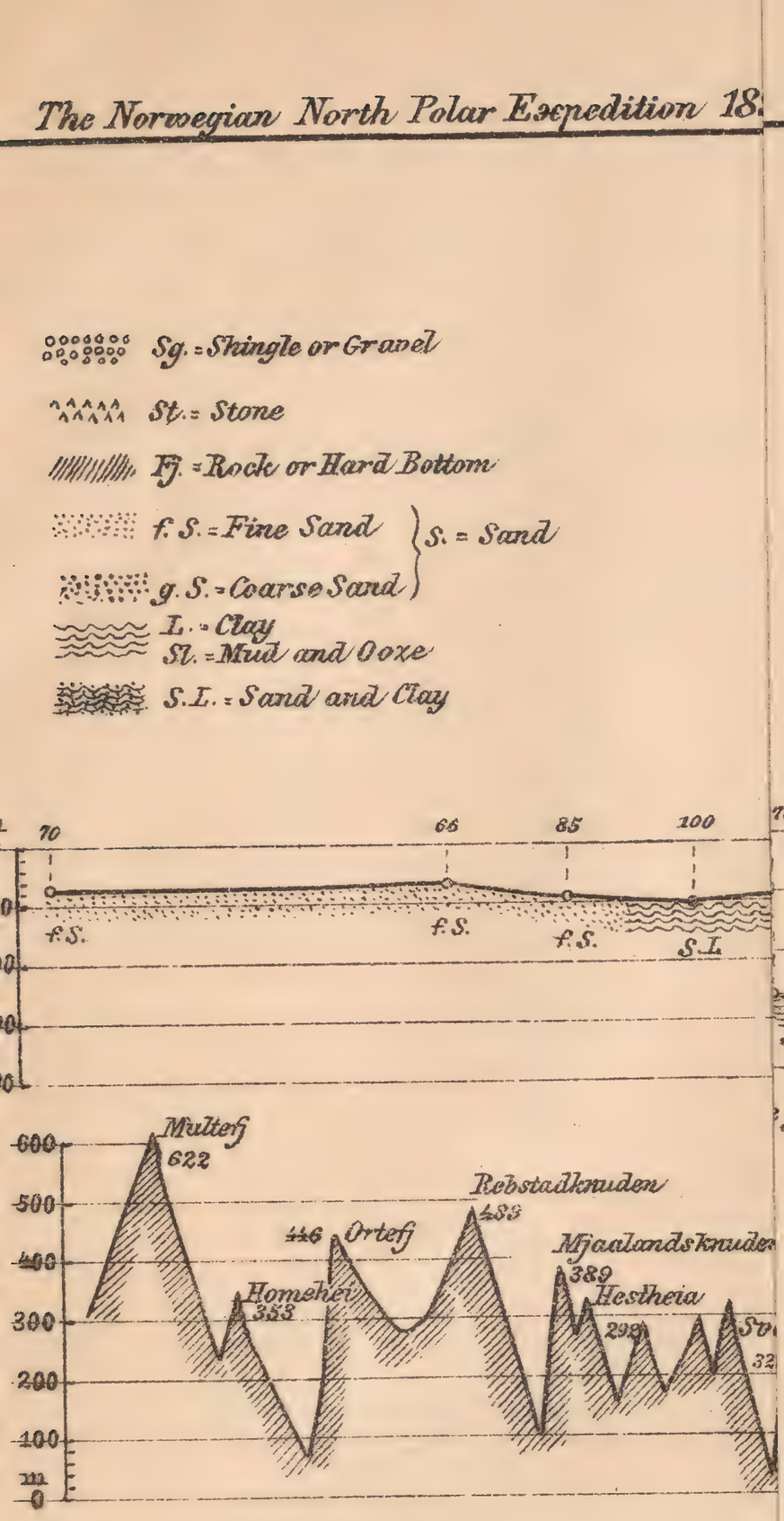
St. = Stone

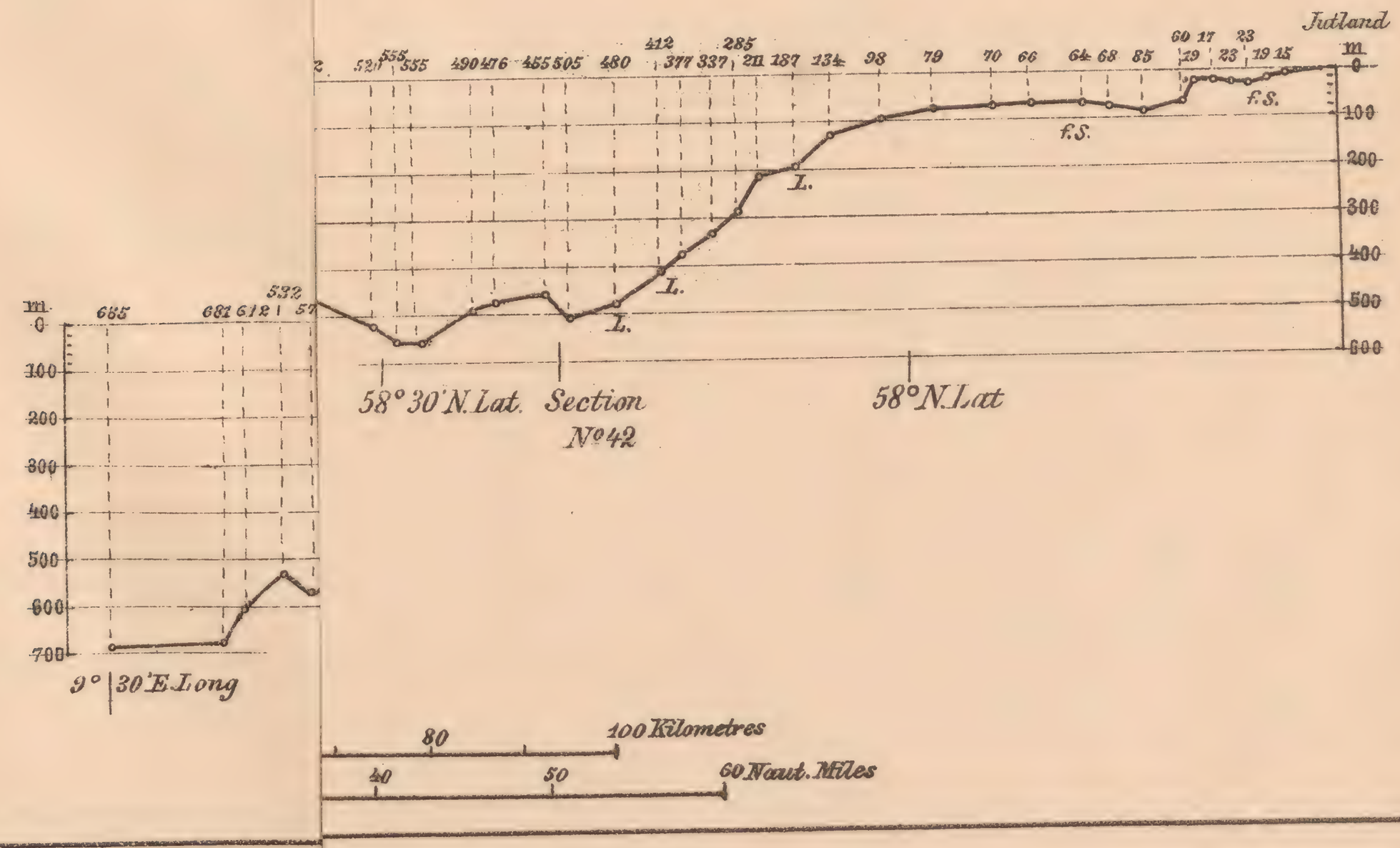
Fj. = Rock or Hard Bottom

f. S. = Fine Sand } S. = Sand
g. S. = Coarse Sand }

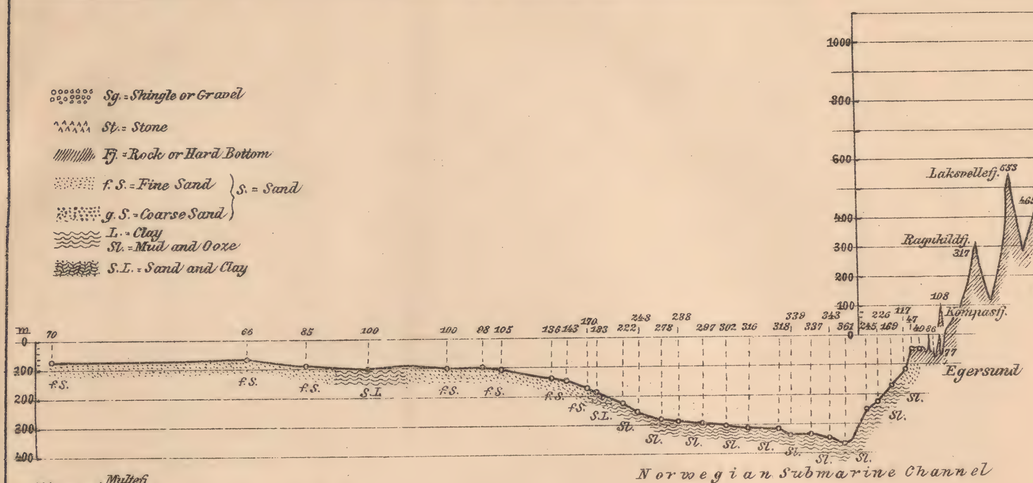
L. = Clay
Sl. = Mud and Ooze

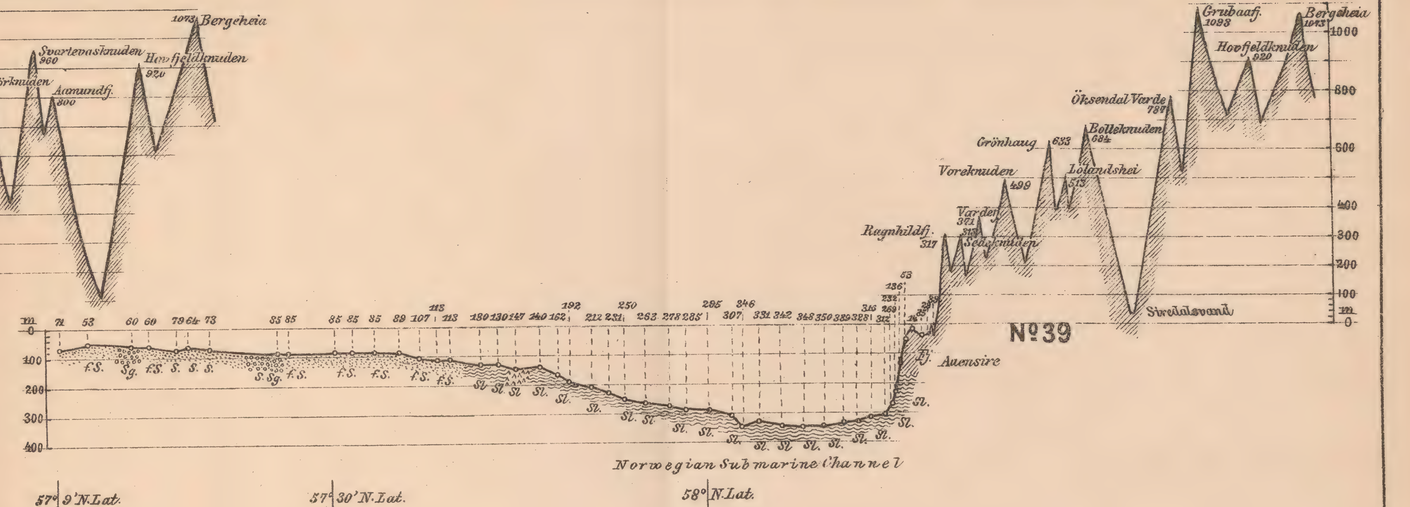
S. L. = Sand and Clay

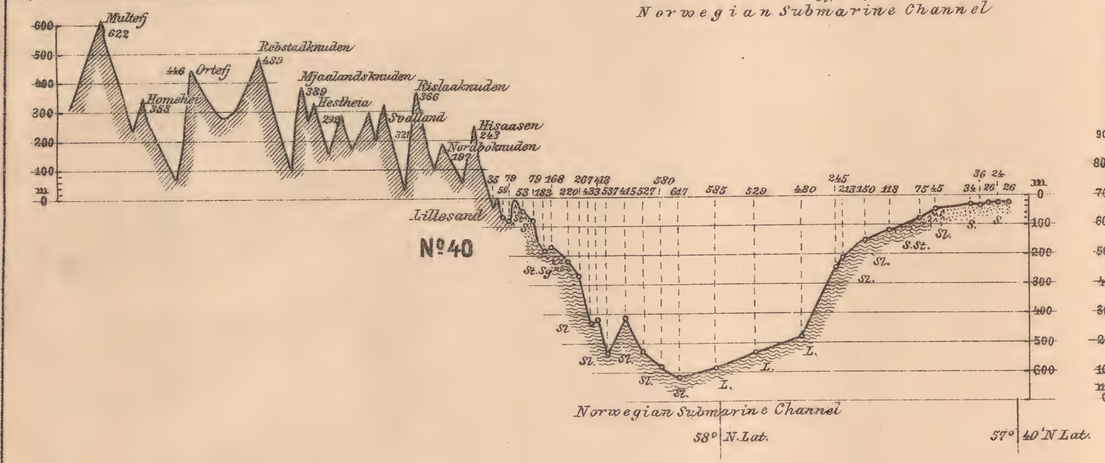


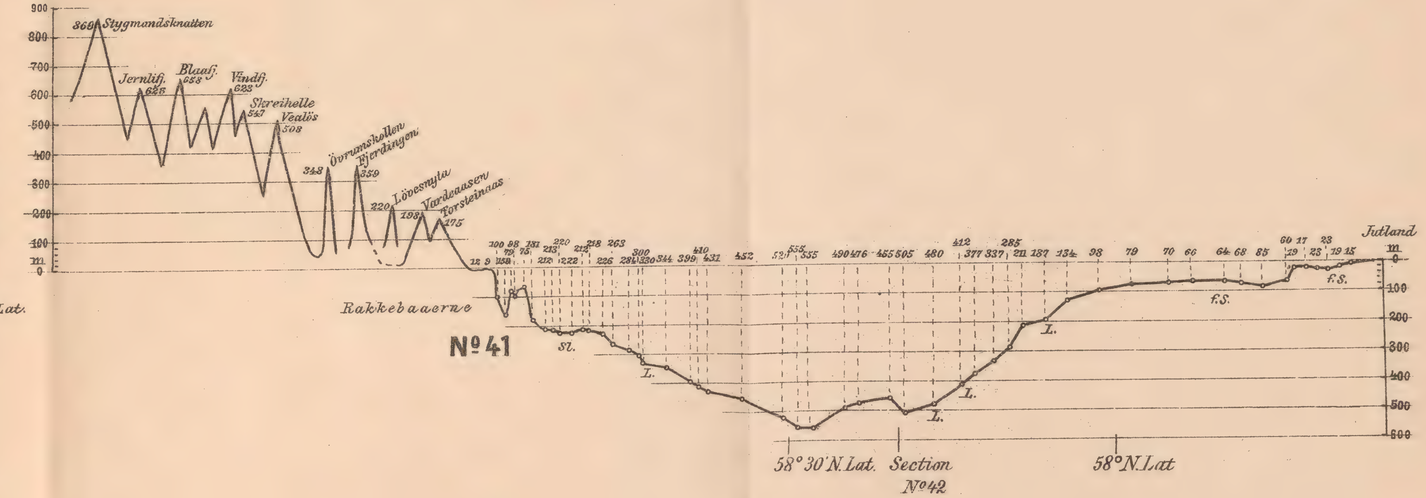


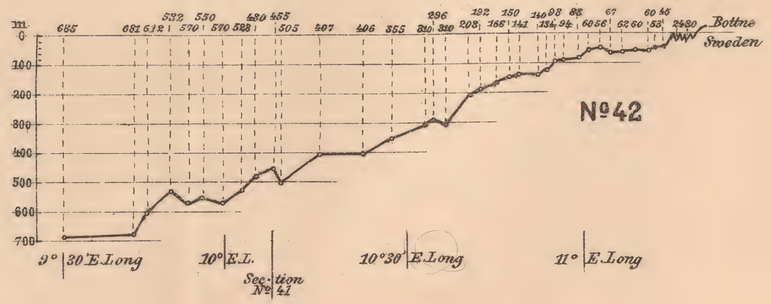
Sg. = Shingle or Gravel
St. = Stone
Fj. = Rock or Hard Bottom
f.S. = Fine Sand } S. = Sand
g.S. = Coarse Sand }
L. = Clay
Sl. = Mud and Ooze
S.L. = Sand and Clay





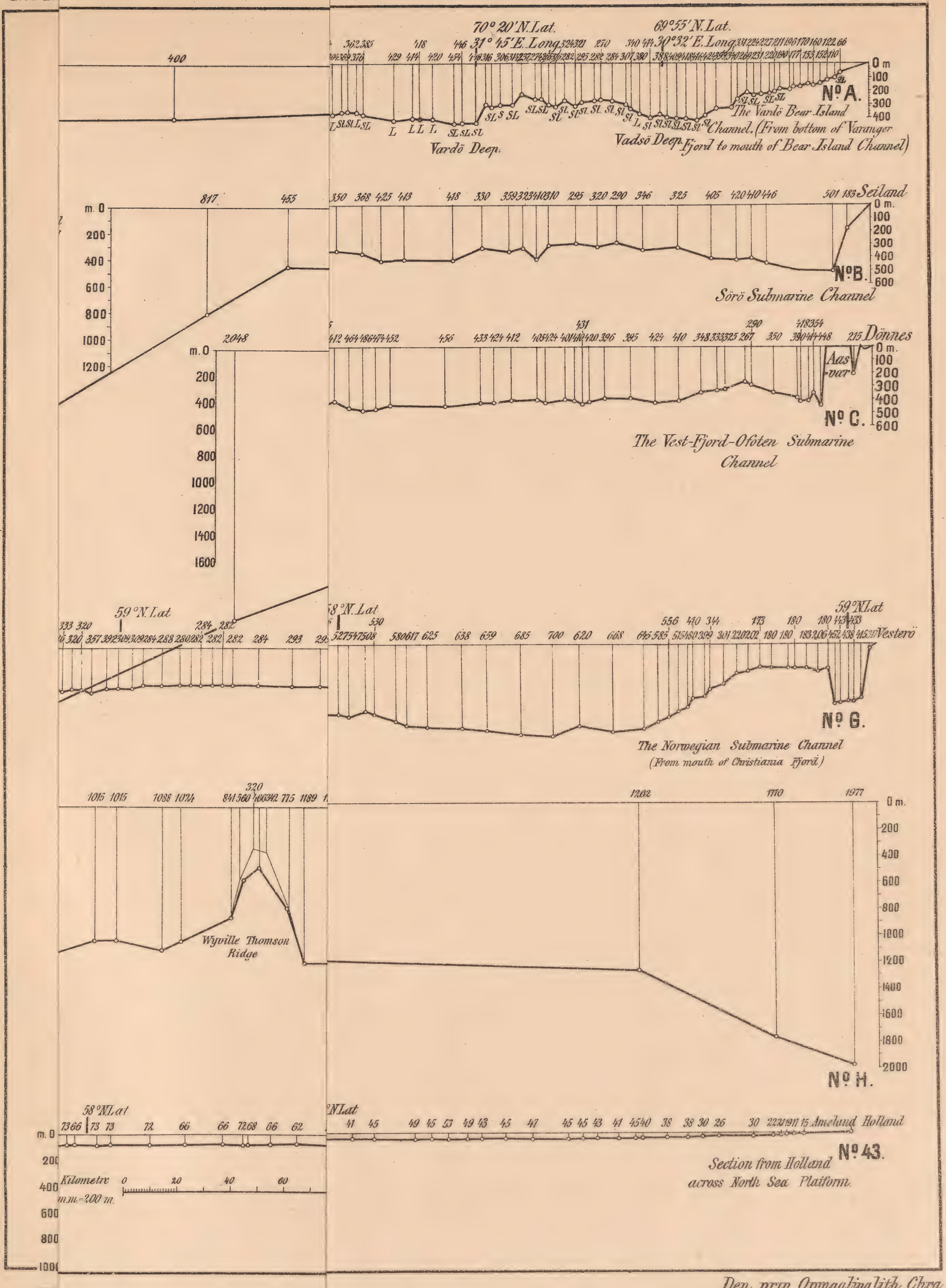




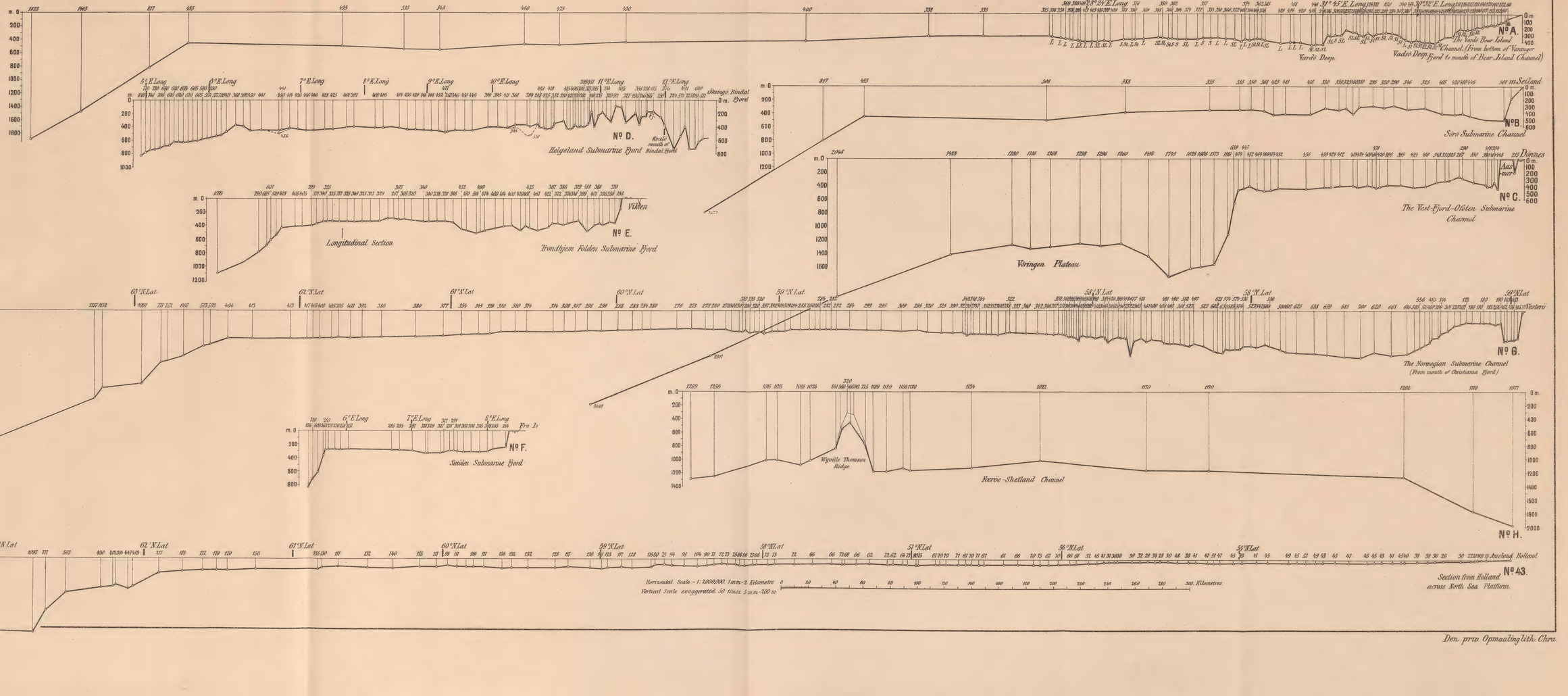


Horizontal Scale = 1:1000000 1 m.m. = 1 Kilometre
Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.

0 10 20 40 60 80 100 Kilometres
0 10 20 30 40 50 60 Naut. Miles



Den prv. Opmaaling lith. Chra.



Den. prav. Opmaaling 16th. Chra.

54 183 223 273 229 248 238 420 552

S S S S S Fj.
121 117 106 130 95 123 60 101 101 95 84 71 73 60

433 477 399 354 243 42 2 49 57 42 119 60 64

Hoy — Fj. — s. Ronaldsby — Orkney Islands

500 400 300 200 100 m. 0 100 200 300 400

8 512 494 521 529 384 576 557 547

97 84 84 73 71 86 80 66 53 34 32

Ben Spuno 794 — Craig Reavagh 481 461 — Fashven 453 — Scrivie Ben 366 — 351 294 155

Cape Wrath — Scotland

700 600 500 400 300 200 100 m. 0 100 200 300 400 500 600

ighest part of
nson Ridge

W y w i l l e

497 428 459 448 490

S.L. S.St. S.St. S.L. S. St

the highest part
across the Fœroes.

162 194 171 169 160 207 282 303 303 382 479 850

700 600 500 400 300 200 100 m. 0 100 200 300 400 500 600 700 800

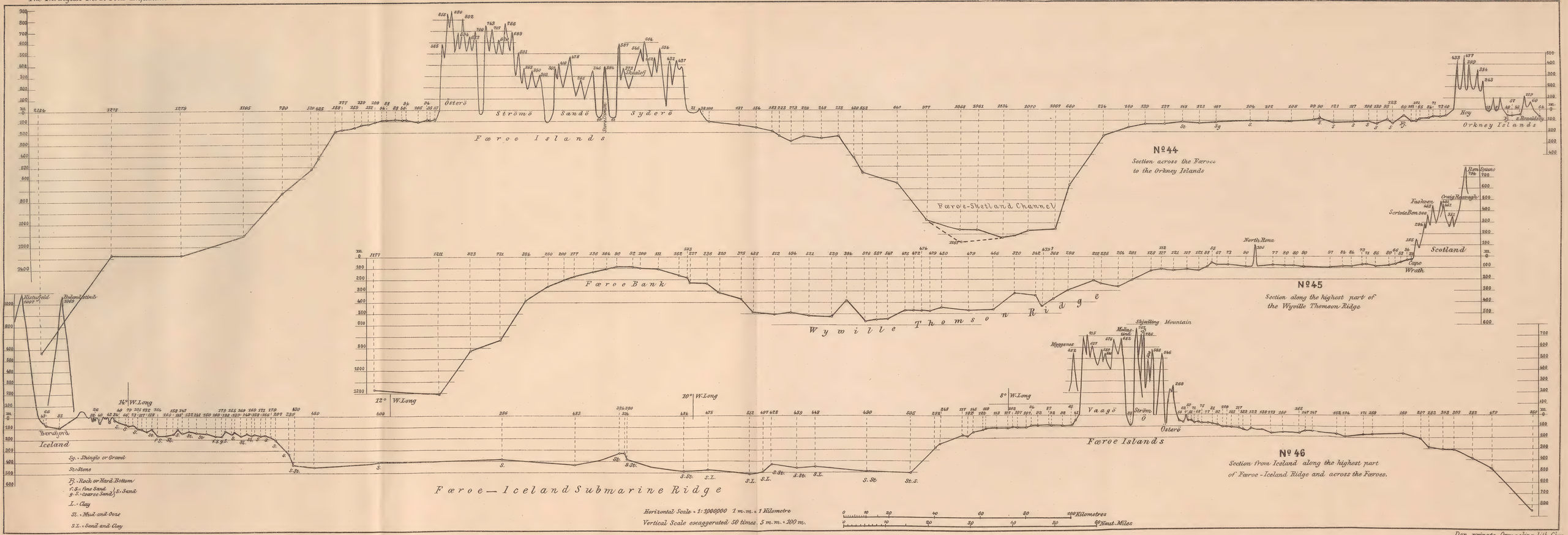
1 Kilometre

5 m.m. = 100 m.

0 10 20

0 10

Den private Opmaaling lith. Chra.



№44

Section across the Færoes to the Orkney Islands

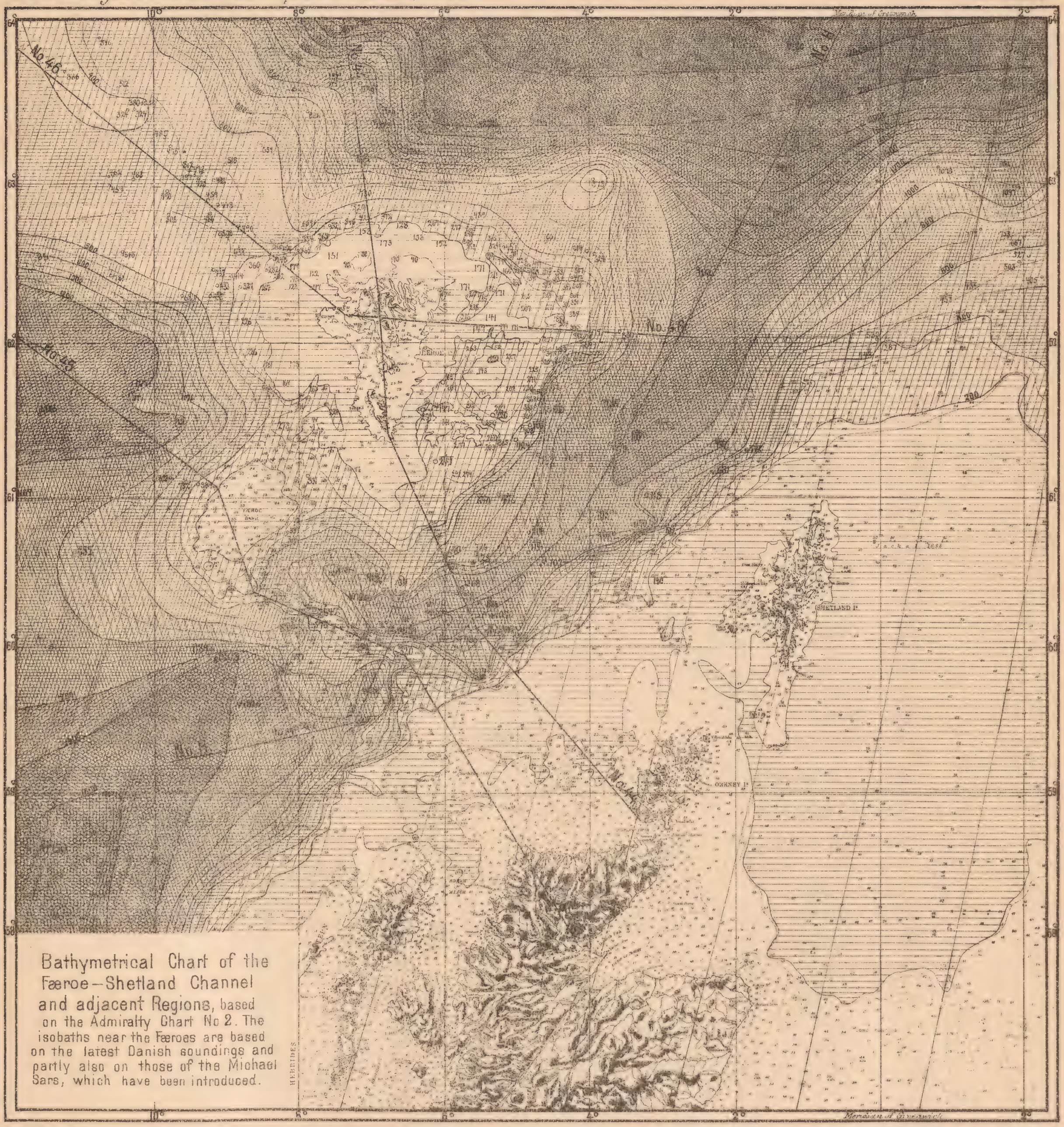
№45

Section along the highest part of the Wyville Thomson Ridge

№46

Section from Iceland along the highest part of Færoe-Iceland Ridge and across the Færoes.

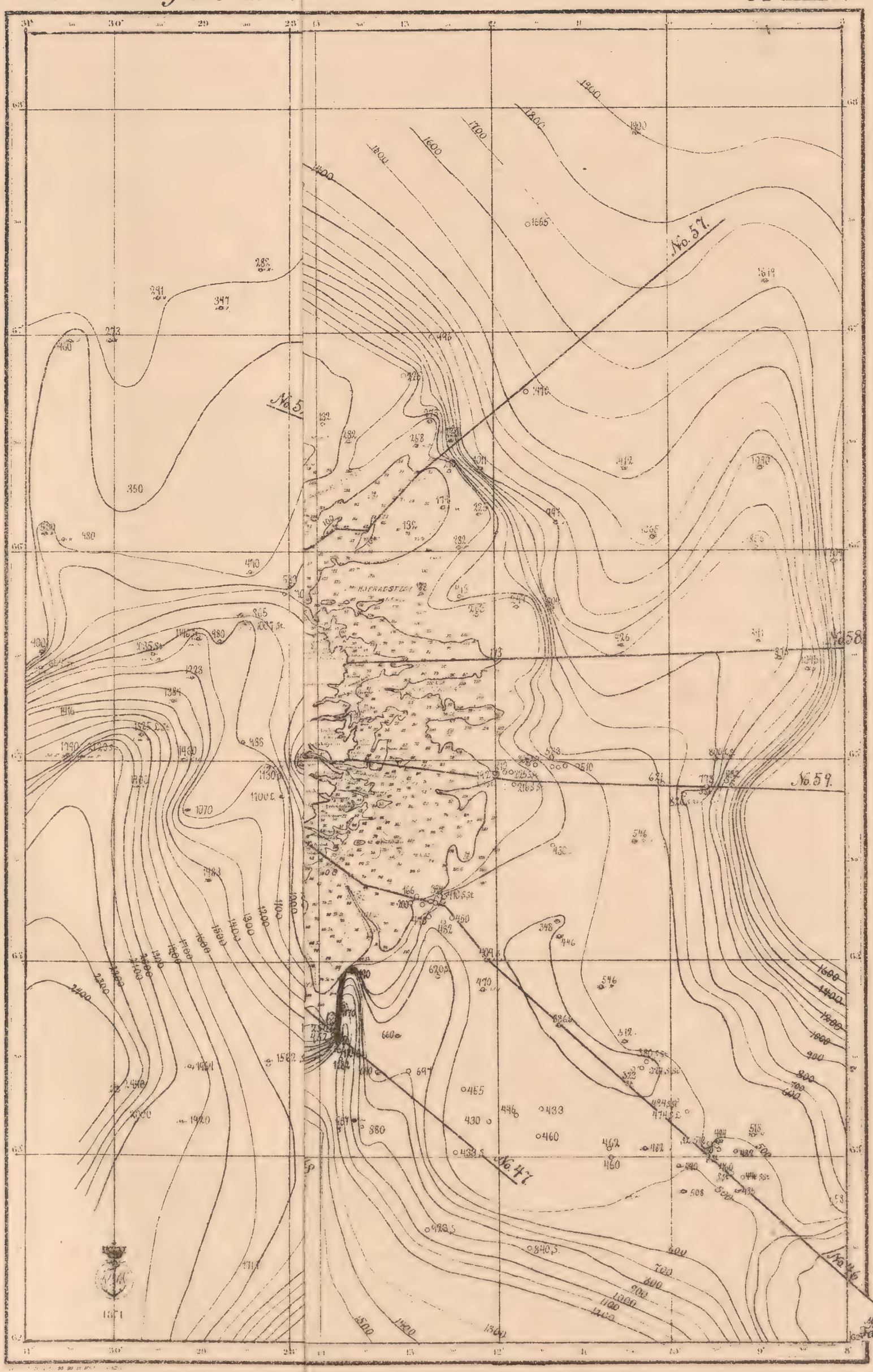
Den. private Opmaaling lith. Chra



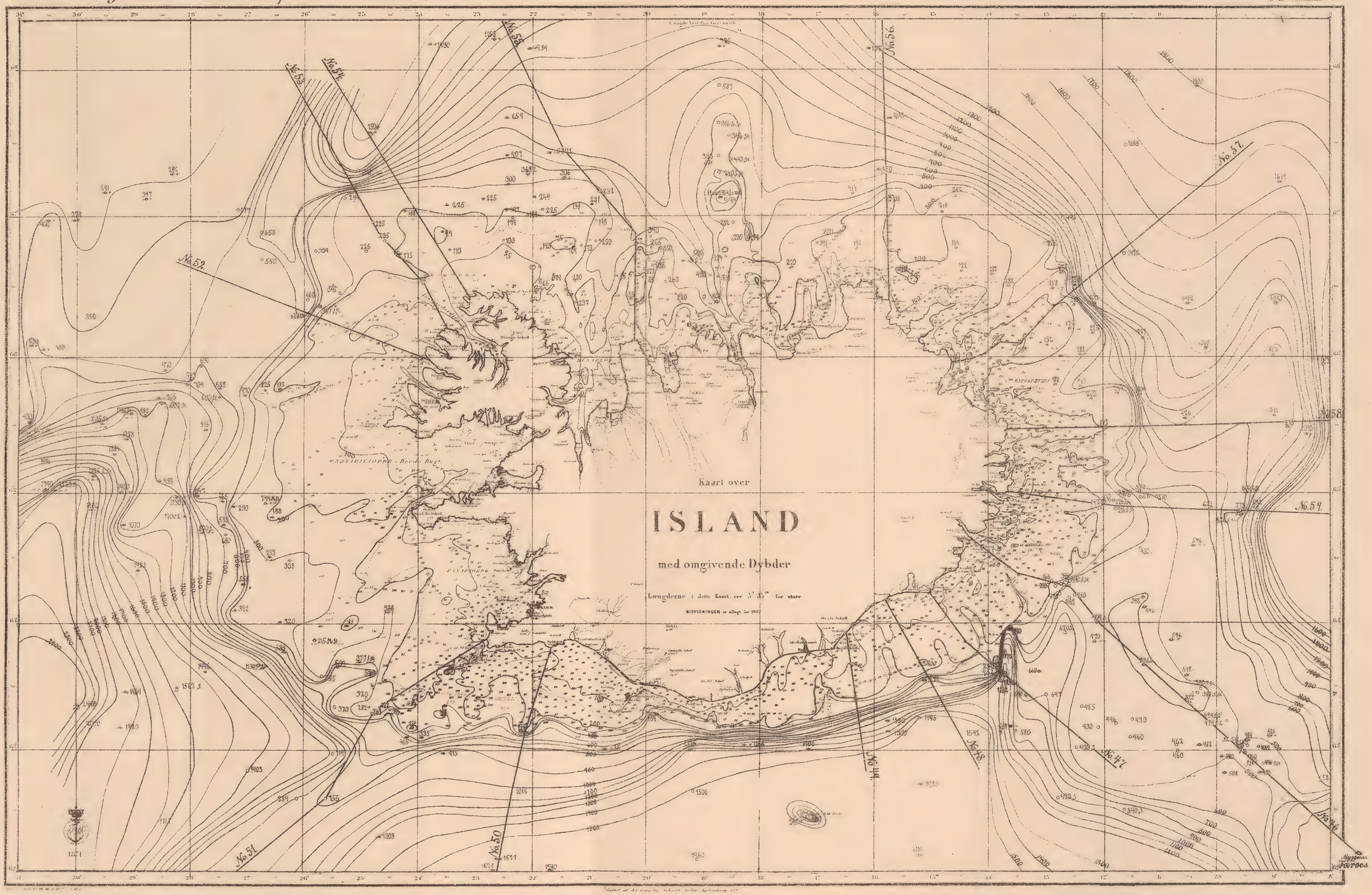
Bathymetrical Chart of the Færoe–Shetland Channel and adjacent Regions, based on the Admiralty Chart No 2. The isobaths near the Færoes are based on the latest Danish soundings and partly also on those of the Michael Sars, which have been introduced.

The Norwegian Nort

Pl. XXIV.

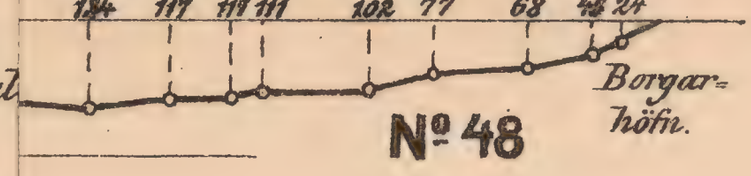


Bath*chiv, Copenhagen The soundings*
of the latest Danish Soundings.

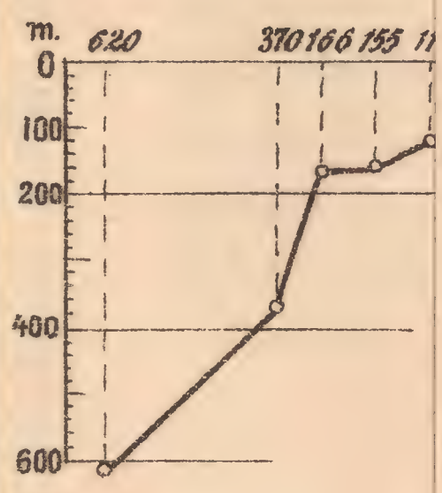


Bathymetrical Chart of the Sea round Iceland, based on the chart N.º 114 of Kongelige Sökort-Archiv, Copenhagen The soundings of the Michael Sars have been introduced. The isobaths north of Huna-Floi and Eya Fjord are based on the latest Danish Soundings.

Horizontal Scal
Vertical Scale



№ 48



№ 47

№ 49

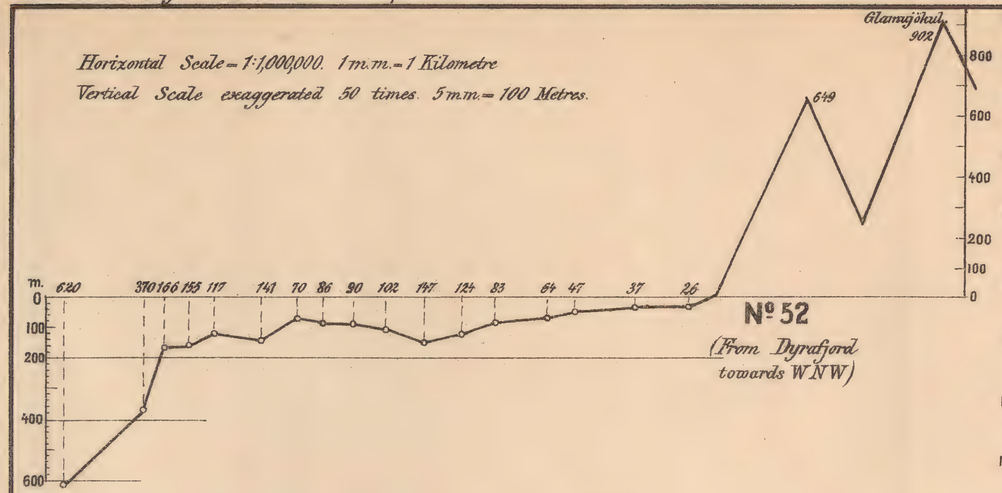
(From near Ingolfshöfdi towards S b E).

№ 51

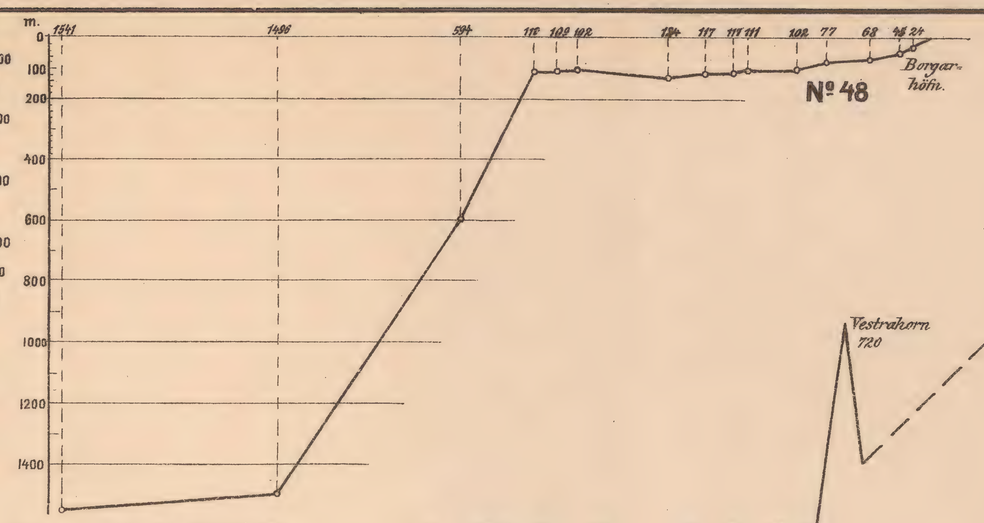
(From Reykjanes towards S W).

Den private Opmaaling

Horizontal Scale = 1:1,000,000. 1 m.m. = 1 Kilometre
Vertical Scale exaggerated 50 times. 5 m.m. = 100 Metres.



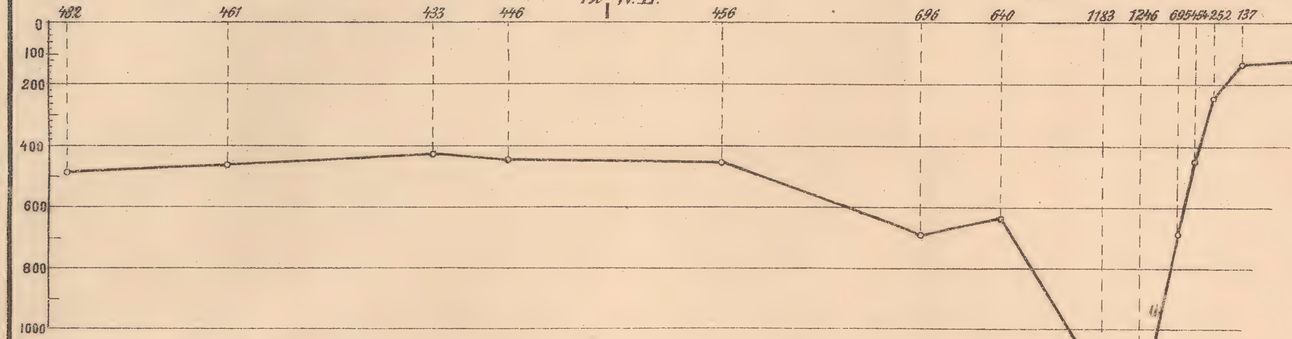
Nº 52
(From Dyrafjord towards WNW)

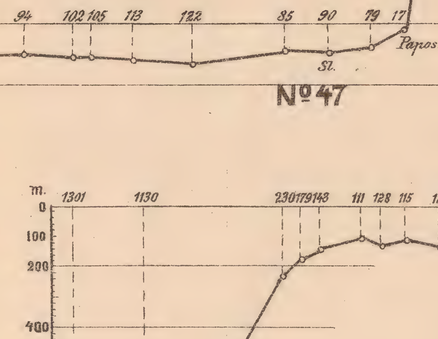


Nº 48

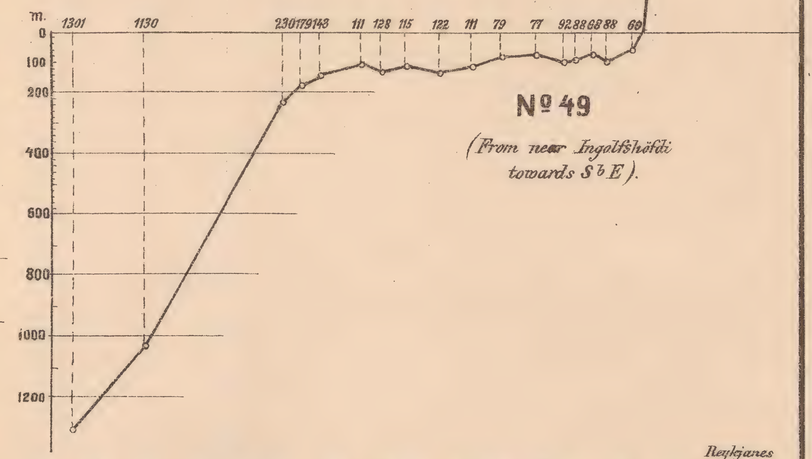
Snæfell 1822
Örafajökul. 1967.
Storhöfdi. 1446
Vestrahorn 720

12° W.L.

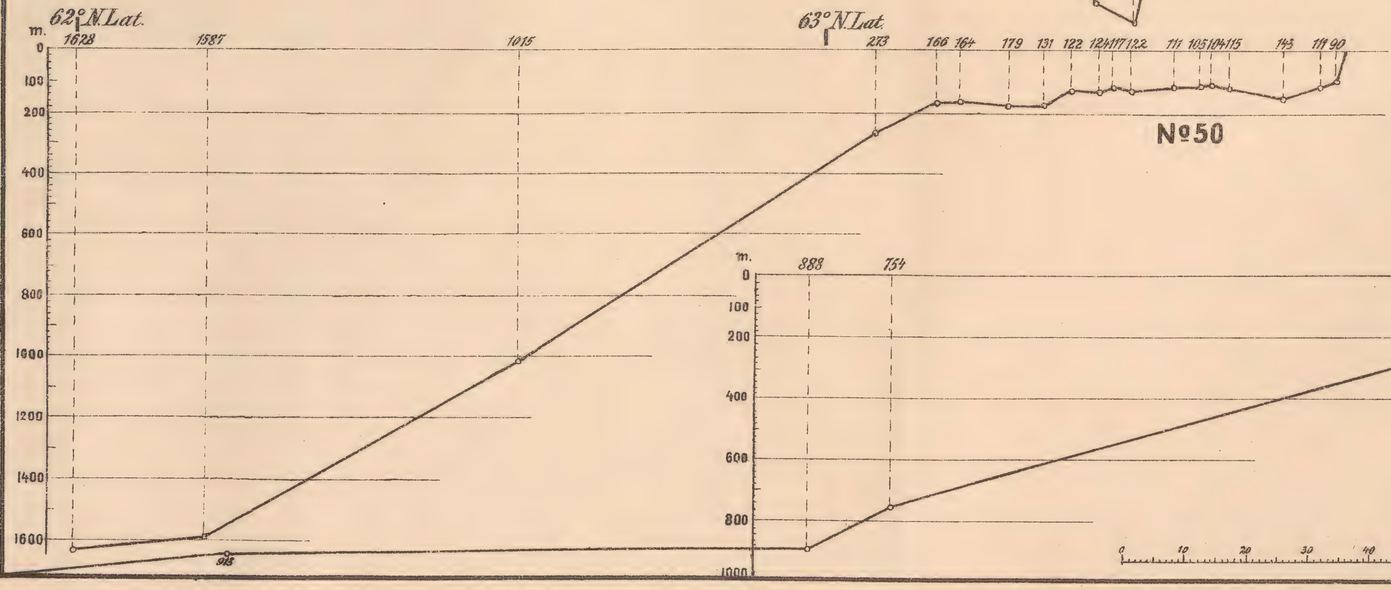




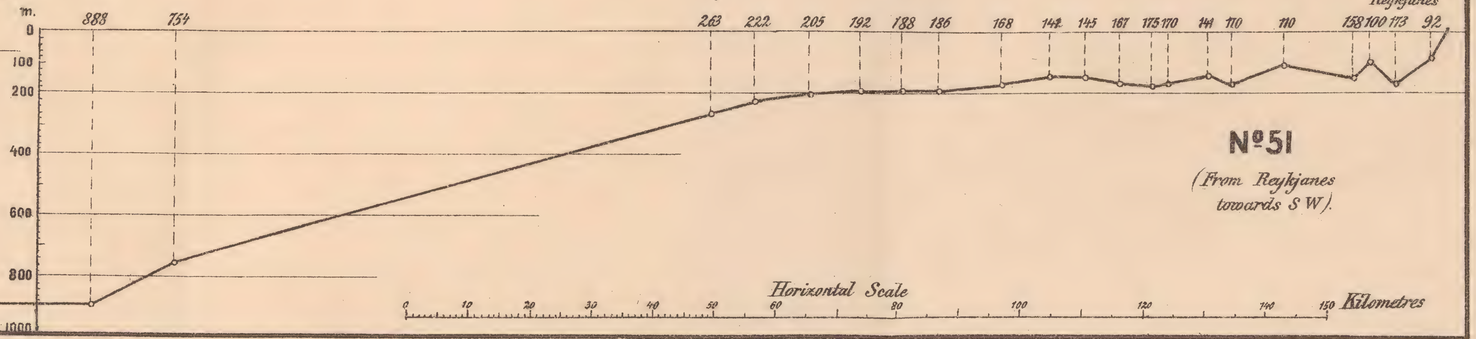
Nº 47



Nº 49
(From near Ingolfshöfdi towards S b E).



Nº 50

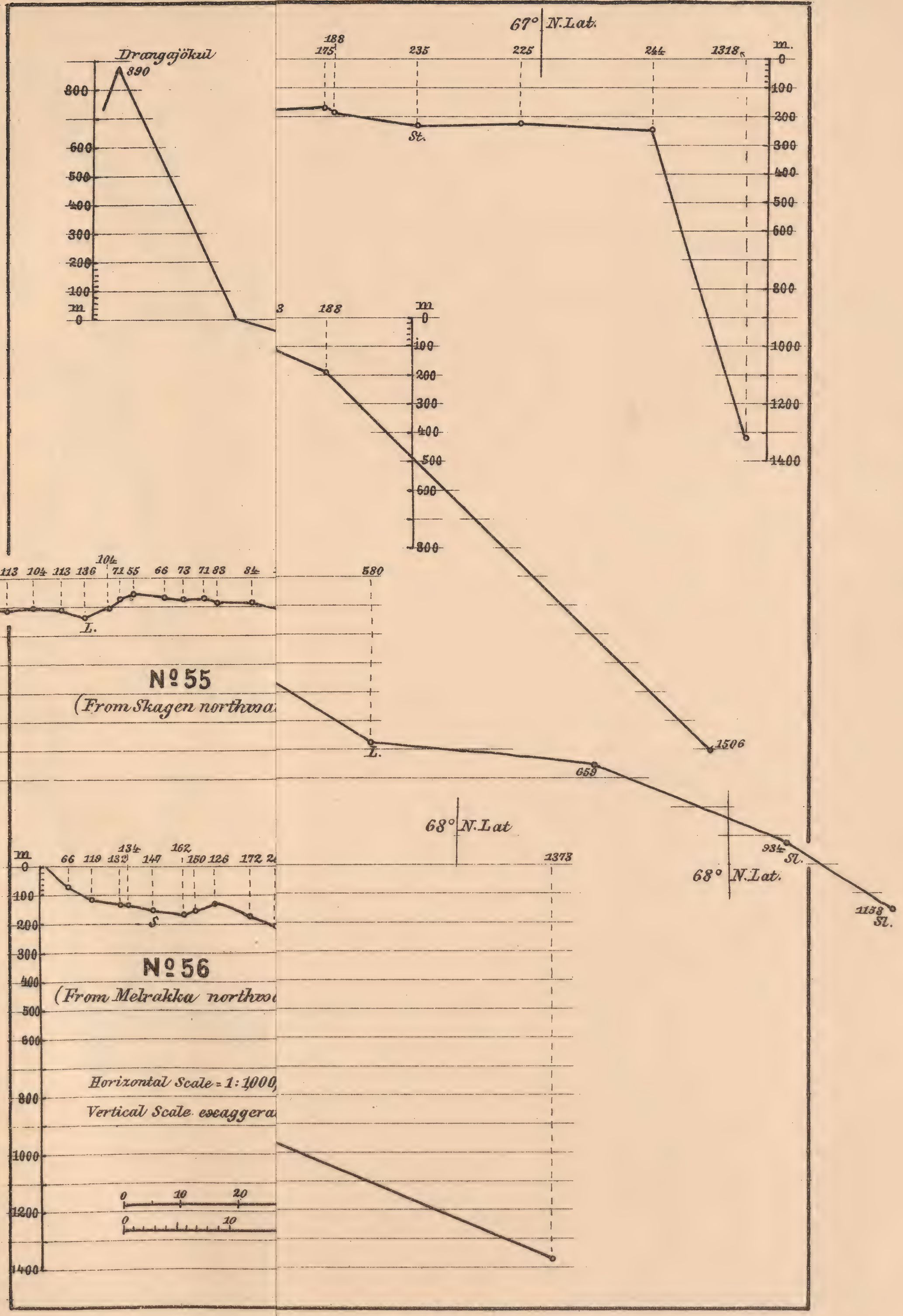


Nº 51
(From Reykjanes towards S W).

Horizontal Scale
0 10 20 30 40 50 60 80 100 120 140 150 Kilometres

Den private Opmaaling

Reversed continuation of Section Nº 51
1230
1367

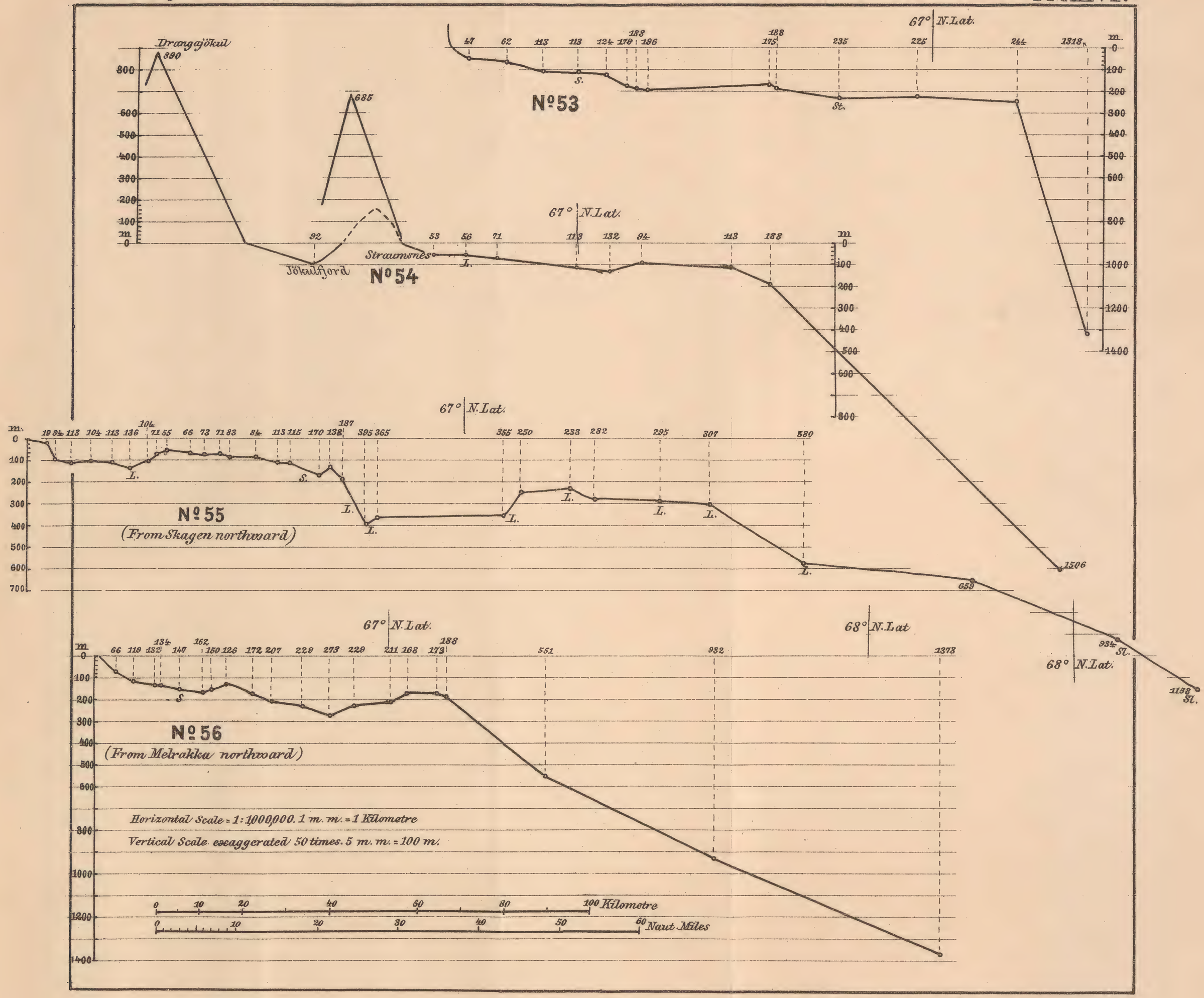


Nº 55

(From Skagen northwa

Nº 56

(From Melrakka northwa

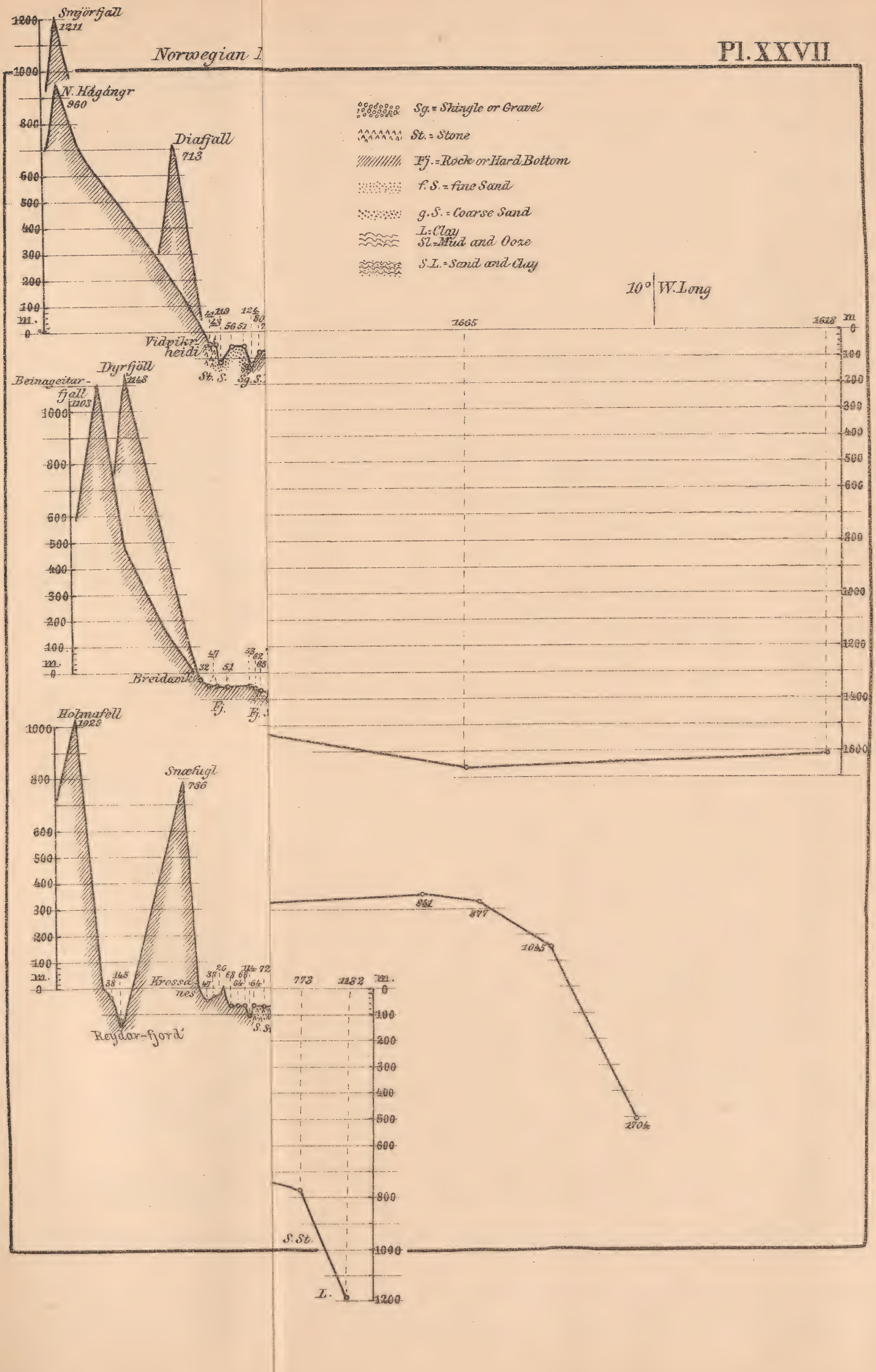

67° N.Lat.
Drangajökul
890
685
47 62 113 113 124 178 188 196 175 188 235 225 244 1318
m. 0 100 200 300 400 500 600 800 1000 1200 1400
S.
St.
Nº53
92
Jökulfjord
Nº54
53 56 71 113 132 94 113 188
Straumsnes
L.
m 0 100 200 300 400 500 600 800
67° N.Lat.
m. 0 100 200 300 400 500 600 700
19 94 113 104 113 136 104 71 55 66 73 71 83 84 113 115 170 138 187 395 365 355 250 233 232 295 307 580
L. S. L. L. L. L. L. L. L.
Nº55
(From Skagen northward)
1506
659
67° N.Lat.
68° N.Lat
m 0 100 200 300 400 500 600 800 1000 1200 1400
66 119 132 134 147 162 150 126 172 207 229 273 229 211 168 188 551 932 1373
S.
Nº56
(From Melrakka northward)
Horizontal Scale = 1:1,000,000. 1 m.m. = 1 Kilometre
Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.
0 10 20 40 60 80 100 Kilometre
0 10 20 30 40 50 60 Naut. Miles
68° N.Lat.
934 St.
1138 St.

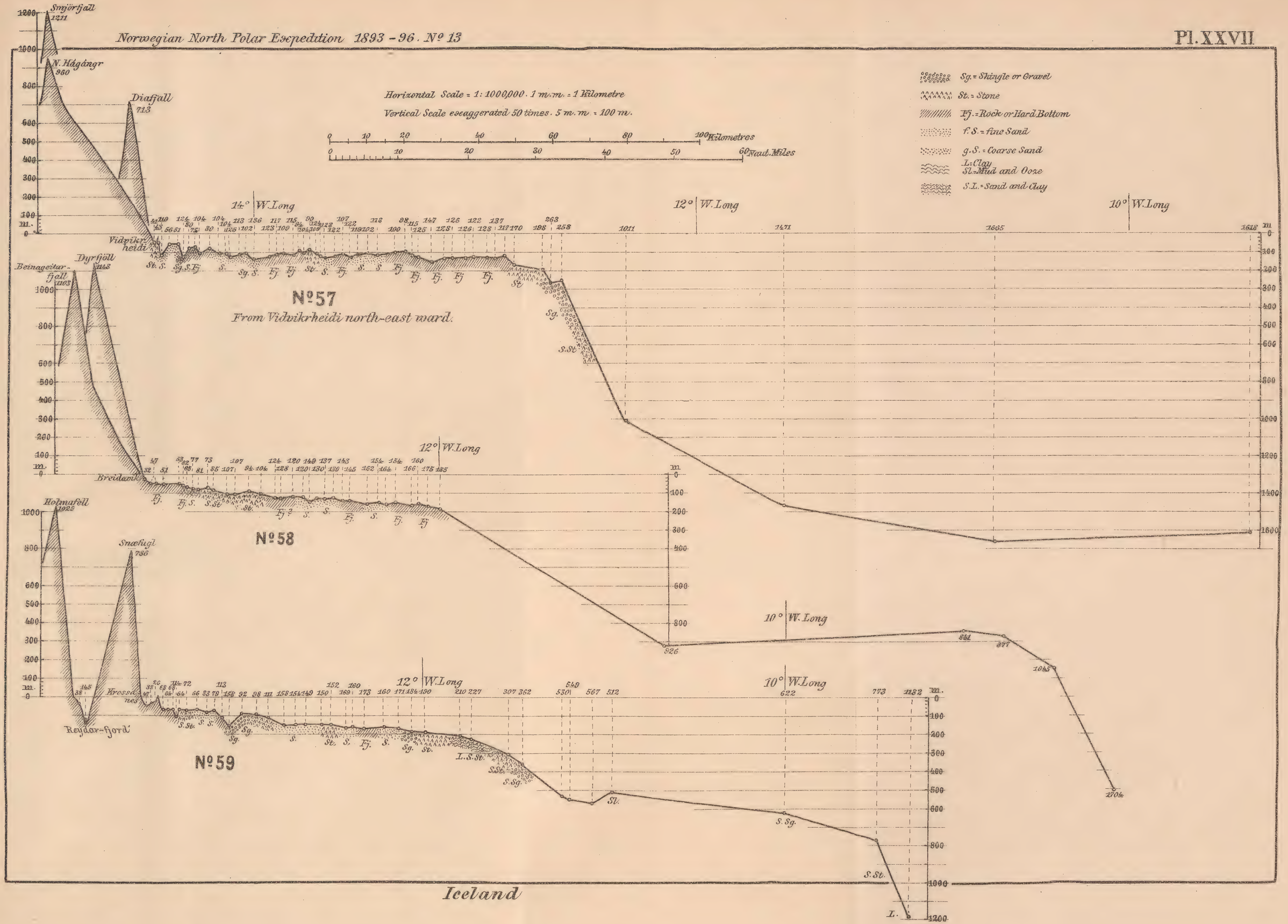
Iceland

Norwegian

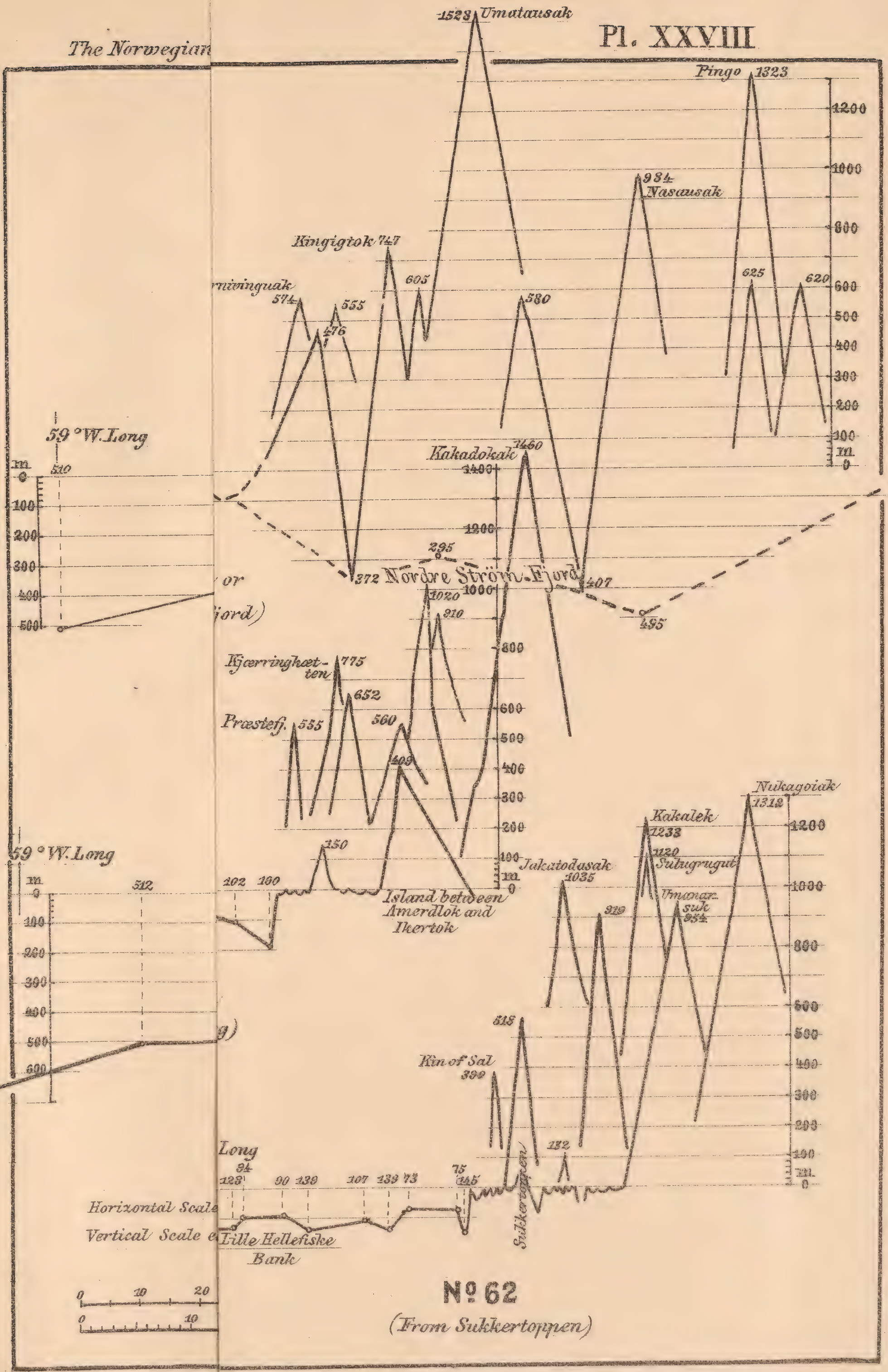
Sg. = Shingle or Gravel
St. = Stone
Fj. = Rock or Hard Bottom
f. S. = fine Sand
g. S. = Coarse Sand
L. = Clay
Sl. = Mud and Ooze
S. L. = Sand and Clay

10° W. Long




Horizontal Scale = 1: 1000,000. 1 m.m. = 1 Kilometre
Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.
Kilometres
Naut. Miles
Sg. = Shingle or Gravel
St. = Stone
Fj. = Rock or Hard Bottom
f. S. = fine Sand
g. S. = Coarse Sand
L. = Clay
Sl. = Mud and Ooze
S. L. = Sand and Clay
Smjörfjall 1211
N. Hágángr 960
Diafjall 713
Vidvikrheidi
Dyrfjöll 1148
Beinageitarfjall 1103
Breidavik
Holmafell 1926
Snæfugl 786
Krossanes
Reydar-fjord
14° W. Long
12° W. Long
10° W. Long
Nº 57
From Vidvikrheidi north-east ward.
Nº 58
Nº 59
Iceland

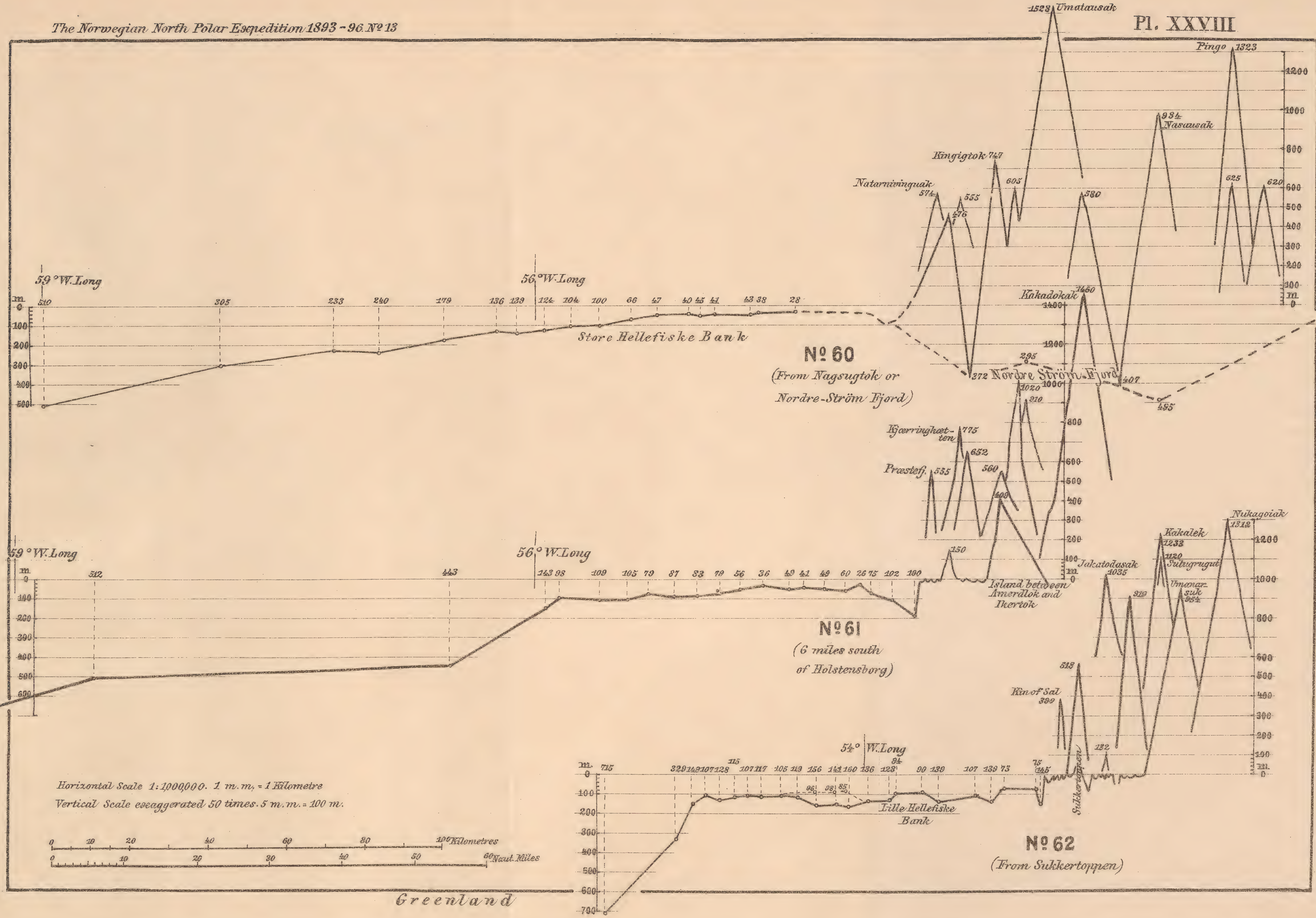
Pl. XXVIII



No 62

(From Sukkertoppen)

Pl. XXVIII

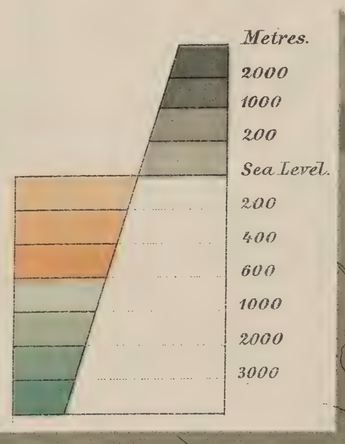

59° W. Long
56° W. Long
Store Hellefiske Bank
№ 60
(From Nagsugtok or Nordre-Ström Fjord)
Nordre Ström Fjord
Umatausak
Pingo
Nasausak
Kingigtok
Natarnivinguak
Kakadokak
Kjærringhætten
Præstefj.
Island between Amerdlok and Ikertok
№ 61
(6 miles south of Holstensborg)
Jakatodasak
Kakalek
Sulugrugut
Umanarsuk
Nukagoiak
Kin of Sal
Sukkertoppen
54° W. Long
Lille Hellefiske Bank
№ 62
(From Sukkertoppen)
Horizontal Scale 1:1,000,000. 1 m.m. = 1 Kilometre
Vertical Scale exaggerated 50 times. 5 m.m. = 100 m.
Kilometres
Naut. Miles
Greenland

Bathymetrical Chart of NORTH POLAR SEAS

By

Fridtjof Nansen.

Depths are given in Metres.
Isobaths are drawn for 200, 400, 600, 800, 1000, 1500, 2000, 2500, 3000, 3500 Metres.
At some places the 100 metres-contour and the 300 metres-contour are drawn with dotted lines.
The thick straight lines thus, No 62 indicate the sections reproduced in Pls. X, XII et seq. The Figures (No 62) indicate the numbers of the sections.



No 1 No 2 No 3 No 4 No 5 No 6 No 7 No 8 No 9 No A No B No 43 No 60 No 61 No 62

160° 170° 180° 170° 160° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40° 30° 20° 10° 0° Greenwich Meridian 10 20 30

90° 89° 88° 87° 86° 85° 84° 83° 82° 81° 80° 79° 78° 77° 76° 75° 74° 73° 72° 71° 70° 69° 68° 67° 66° 65° 64° 63° 62° 61° 60°

Kart- og Litografiavdelingen Kr.a.

Long. West of Gr. — Gr. M. — Longitude East of Greenwich

BATHYMETRICAL AND HYPSOMETRICAL MAP OF NORWAY

SCALE 1 : 2,400,000

Sea Level
100 Metres
200 „
300 „
400 „
500 „
600 „
700 „
800 „
900 „
1000 „
1200 „
1400 „
1600 „
1800 „
2000 „
3000 „
Below 3000 Metres

Glaciers
2500 Metres
2000 „
1500 „
1000 „
500 „
Sea Level
Lakes

100 50 0 50 100
Kilometres
20 0 20 40 60 80 100
Nautical Miles

Longitude East of Greenwich
Kristiania 0 Meridian

Kristiania litografiske Aktiebolag.

Long. West of Gr. — Gr. M. — Longitude East of Greenwich

№ A. № B. № C. № D. № E. № F.

№ 1 … № 40

Long Sections

Fjord

Trough

Bank

Deep

Channel

Vest Fjord

Haltan Bank

Skagen

Utsire

Jæderen

Vesteren

Trænen

Smulen

Fyllingen

Ryvingen

Lindesnæs

Lister

Farsund

Egersund

Stavanger

Sandnæs

Arendal

Tvedestrand

Risør

Grimstad

Lillesand

Kristiansand

Mandal

Flekkefjord

Farsund

Egersund

Stavanger

Haugesund

Bergen

Florø

Sandefjord

Tønsberg

Fredrikshald

Kristiania

Drammen

Hougesund

Hammerfest

Tromsø

Narvik

Namsos

Trondhjem

Christiansund

Molde

Aalesund

Sulen

Stadtlandet

Lindesnæs

Archæan rocks.

Granite and syenite.

Porphyrite.

Gabbro, amphibolite, diabase, etc.

Crystalline schists of uncertain age.

Cambrian and Silurian rocks.

Sandstones, etc. of uncertain age.

Sandstones, etc. of Gaisa System, Finnmarken.

Coast Platform (Strand Flat) with skerries standing near or slightly above present sea-level.

Continental Shelf standing above 200 metres contour, Any coast north of 62° N. Lat.

The rocks in Finland, and southeastern Sweden are not indicated.

BATHYMETRICAL AND HYPSOMETRICAL MAP OF NORWAY

SCALE 1 : 2,400,000

Fridtj. Nansen.

Sea Level
100 Metres
200 „
300 „
400 „
500 „
600 „
700 „
800 „
900 „
1000 „
1200 „
1400 „
1600 „
1800 „
2000 „
3000 „
Below 3000 Metres

Glaciers
2500 Metres
2000 „
1500 „
1000 „
500 „
Sea Level
Lakes

100 50 0 50 100 Kilometres

20 0 20 40 60 80 100 Nautical Miles

Longitude East of Greenwich

Kristiania 0 Meridian

Kristiania lith. Aktiebolag.

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